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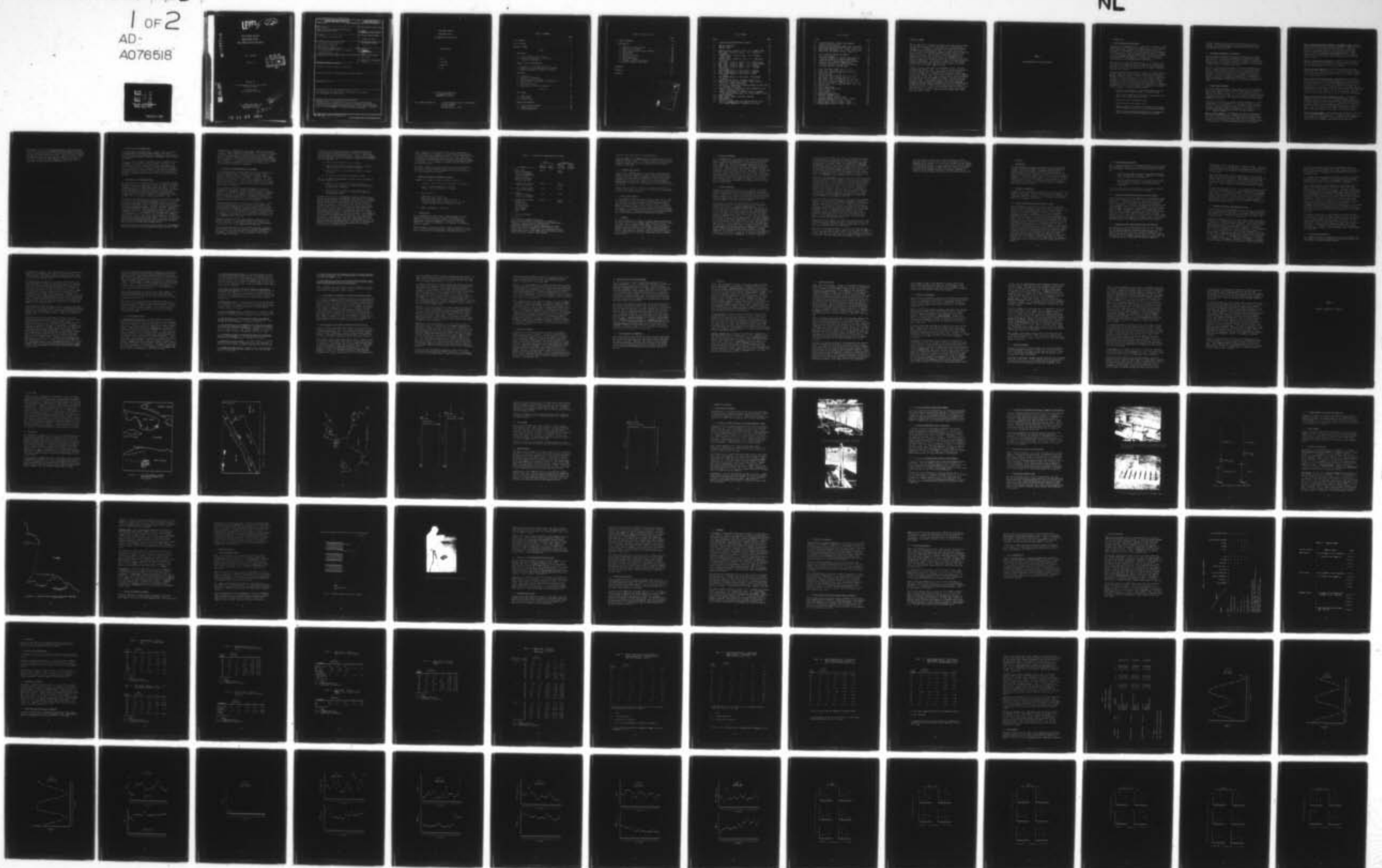

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PILOT WATER QUALITY MONITORING STUDY SAN FRANCISCO BAY AND DELTA

FINAL REPORT

October 1979

Prepared for

U.S. Army Engineer District, San Francisco
Corps of Engineers

211 Main Street
San Francisco, CA 94105

E.H. SMITH & ASSOCIATES, INC.
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THE REPORTS RECOMMEND METHODS TO DETERMINE WATER QUALITY BY USE OF WATER COLUMN, SUSPENDED AND SETTLED PARTICULATES, ARTIFICAL SUBSTRATES AND ANALYSIS OF BIVALVES (CORBICULA FLUMINEA AND MYTILUS EDULIS). THE FINAL STUDY TO DETERMINE WATER QUALITY WITH REPSECT TO SEASONAL AND TIDAL VARIATIONS IS PRESENTED.

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E. Smith

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SEBASTOPOL, CA 95472

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San Francisco, CA 94105

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EXECUTIVE SUMMARY

The U.S. Army Corps of Engineers initiated a pilot water quality study for San Francisco Bay in 1978. The objectives of this study were two-fold: (1) to develop a long-term monitoring program for selected contaminants in San Francisco Bay; and (2) to collect the initial data set of various parameters at preselected sites within San Francisco Bay to be used in the long-term monitoring program. Because of the funding restrictions, replicate field samples and laboratory sub-sampling could not be done. Therefore, it is recommended that a second pilot study be performed to address the questions of replication. After the completion of the second pilot study, a three-year monitoring program is recommended. The program is divided into a more intense one-year Phase I and, based upon the results of Phase I, a two-year Phase II with less frequent sampling periods.

A variety of water column samples were measured at hourly intervals throughout one complete tidal cycle in order to determine the variation of these parameters with tides. Examination of the data reveals that not all water quality parameters varied detectably over a tidal cycle at each sampling site. The salinity regimes at the three sampling stations (Port Chicago, Mare Island, Treasure Island) clearly reflected the different environs where sampling occurred. There were very few recurrent trends in trace element levels between stations throughout the various types of parameters measured. The bivalves *Corbicula fluminea* and *Mytilus edulis* were suspended from racks at three locations in San Francisco Bay. Tissue analysis showed trace metal uptake, but histological and physiological tests indicated stress conditions in the test bivalves at all stations. PCB levels were generally low (below detection), except in water column and sediment samples where levels were high enough to detect.

PART I

RECOMMENDATIONS AND EVALUATION

1. INTRODUCTION

1.1 Overall Purpose of this Project

Previous studies conducted by the U.S. Army Corps of Engineers (Corps of Engineers) in San Francisco Bay (Anderlini et al, 1975) presented factors which were considered to influence the availability of pollutants to invertebrates. These factors were: (1) the magnitude of pollutant input, (2) the rate of pollutant degradation or removal, (3) the physical and chemical characteristics of the receiving waters including suspended particulates, (4) the physical and chemical characteristics of the respective pollutants, and (5) the physiological state of the organism exposed to pollutants.

The objectives of this study were two-fold: (1) to develop a long-term monitoring program for selected contaminants in San Francisco Bay; and (2) to collect the initial data set of various parameters at preselected sites within San Francisco Bay to be used in the long-term monitoring program.

A multitude of factors are involved in designing a long-term sampling program. These may include the type of sample assay, analytical methods, sampling locations or stations, and control of variables in the field. One major emphasis of the pilot study was to examine the suitability of bivalves suspended in the water column as indicator organisms for trace elements and polychlorinated biphenyls (PCBs). In addition, a variety of sample assays were performed to provide background data for each of the preselected sampling sites. Therefore, the results from this study have been used to address the following issues involved in a long-term sampling program.

- Determine the suitability of the bivalve organisms as indicators of trace elements and PCBs in the water column.
- Evaluate which sample assay determinations may be most suitable to the long-term monitoring study.
- Evaluate the sampling methodology used.
- Evaluate the analytical methods used.
- Develop criteria for evaluating the suitability of the preselected sampling sites for the long-term monitoring program.
- Obtain initial background data from each of the preselected sites to be used for the long-term monitoring program.

The report format follows the objectives outlined in this introduction. The discussion format is designed to address each of the aforementioned objectives based upon the observations made and the data obtained from this study.

1.2 Philosophy of Approach to the Project

Many of the field and laboratory techniques used during this study were adopted from the Corps of Engineers' San Francisco Bay Dredge Disposal Study. In some cases techniques were modified to reflect and better achieve the objectives of the study. As much as possible the techniques used in the present study were comparable to those reported in earlier Corps of Engineers' publications.

Although the objectives as previously outlined were addressed in the study, it must be realized that this is a pilot study of very short duration; therefore seasonal variations in both contaminant availabilities and biological responses of test organisms could not be evaluated. Emphasis was placed on the development and evaluation of methods to test short-term uptake and depuration of contaminants in selected organisms. Information was also developed to evaluate long-term monitoring methods in San Francisco Bay and the value of such a study.

1.3 Scope of Work Performed

The overall sampling design was established by the Corps of Engineers. This included sampling frequency, type of sample assay, replication of sample assay, sampling site location, the form and extent of data analysis, and study objectives. E. H. Smith & Associates was contracted to design and perform the sample collection, analytical assays, and the preparation of the report. The sampling program was conducted between February and June 1979.

There were three additions to the data acquisition made by E. H. Smith & Associates: (1) the determination of glycogen/lipid and glycine/taurine ratios for the bivalves, (2) a histological study to establish the state of bivalve gonadal development, and (3) a series of laboratory experiments conducted to determine the suitability of the bivalve *Corbicula fluminea* as a potential indicator organism.

Task 1: Station Location. The sampling stations were preselected by the Corps of Engineers. The pilot sampling station for the central bay (site one) was established on the eastern side of Treasure Island. Site two was established at the Coast Guard pier at the southern tip of Mare Island in the Carquinez Strait area, and site three was located on the barge pier at Concord Naval Weapons Station, Port Chicago.

Task 2: Physical and Chemical Analysis of the Water Column. Analyses were performed for salinity, turbidity, suspended and settleable solids, ammonia- and nitrate-nitrogen, and dissolved oxygen. Samples were collected once each hour during a 24-hour period at each station during the first sampling effort, and once at each station during slack low tide for the remaining three sampling efforts. Trace elements and PCB concentrations were determined once on all samples collected at each station during slack low tide on each of the four sampling efforts.

Task 3: Suspended Particulate Matter. Samples for trace elements and PCBs were collected by separate specially designed pumping systems. Particles were separated into three size classes and each size class was analyzed separately for PCBs and trace elements.

Task 4: Settling Particulates. Particles settling from the water column found in the immediate vicinity of the sediment/water interface were isolated after coring by sectioning frozen core contents. Frozen sections were subsequently analyzed for PCBs, trace elements, ammonia- and nitrate-nitrogen content.

Task 5: Selection of Test Organisms. *Mytilus edulis* was collected in the vicinity of Point Richmond and transplanted to both the Treasure Island and Mare Island sites; *Corbicula fluminea* was transplanted from the lower Sacramento River Delta to the Mare Island and Port Chicago Naval facility sites. These mussels and clams were suspended from floating racks in Nytex bags. Determinations of trace element and PCB burdens were periodically made on pooled, randomly-selected bivalves (same size class) during the course of the study. Glycogen and lipid levels of these bivalves were determined in similarly-harvested transplants. The ratio of free taurine to free glycine was determined simultaneously.

Task 6: Artificial Substrate (Aufwuch) Collection. The artifical substrate rack design follows one developed and widely tested by Alexander Horne for the collection of estuarine Aufwuch communities. Plexiglass frames and supporting glass settling tubes were constructed as collection devices to facilitate trace element content analysis on attached organisms. A similar apparatus was constructed of stainless steel to collect organisms for PCB burden determination. Complementary data such as total organic carbon, chlorophyll a and volatile solids levels were obtained in conjunction with contaminant data.

Task 7: Bottom Sediments. Bottom sediment was collected by a PVC corer for trace element determination, and by a stainless steel core to obtain samples for PCB determination. Nitrogen levels (as ammonia and nitrate) were also determined. Sediment size analysis and faunal identification and enumeration were conducted for each site.

The material in this report has been presented in two parts by study objectives. In Part I, the recommended long-term sampling design is first, followed by the evaluation of sampling and analytical techniques, and station location evaluation criteria. Part II consists of methods and materials used for the study and the presentation of data. An internal cross reference system has been incorporated into Part I of this report to allow the reader immediate access to those sampling techniques, data and observations presented in Part II.

2. SAMPLING DESIGN RECOMMENDATIONS

A long-term sampling program similar in scope to this pilot study is described below. The program has been designed to facilitate acquisition of data which should allow an examination of the relationship of suspended organisms (bivalves) to contaminant levels in their environment.

This pilot study was primarily designed to obtain information for the development of a long-term monitoring program. Specifically, the information was obtained to allow some evaluation of sampling and analytical methodology, suitability of the test organisms used and station evaluation criteria; in addition, other results and observations made during this study are reported. Evaluations are presented separately in Section 3 of Part I, and in Part II which describes materials and methods used in the pilot study and the results thereby obtained.

2.1 Explanation of the Sampling Design

As previously stated, the primary objective of the proposed long-term monitoring project is to examine and evaluate the relationship between suspended organisms and contaminants in their environment. Sources of contaminants (in this context, trace elements and PCBs) to the suspended organisms would include the water column, suspended and recently-settled particulates and, possibly, sediments. Additional data include nonfilterable residue; standard physical measurements such as temperature, D.O., salinity, turbidity; and ammonia- and nitrate-nitrogen - all of which were collected from the water column.

The proposed long-term monitoring project should be preceded by a second pilot study. This second study would address the question of the number of field replicates and laboratory subsamples necessary to assure a sound monitoring program. During this present study, funding was not available to take sufficient field replicates to establish the variability of the various parameters sampled. Likewise, laboratory subsampling could not be carried out to verify analytical precision. Therefore, we recommend a second pilot study (see Appendix B) before starting the long-term project. It is recommended that the sampling techniques used in this present pilot study (Section 5) be retained, after suggested modifications (Section 3) are incorporated and applied in the second pilot study and long-term monitoring program. In addition to these data, weather data (including precipitation, wind velocity and solar irradiance) and tidal height data would be useful as background information, and can be easily recorded using automated devices.

Based upon the results of this pilot study and those of the recommended second pilot study, the long-term sampling program is designed to span

three years and is separated into two phases. Phase I would consist of intensive monthly sampling and measurement of a suite of environmental variables. Phase I data would then be analyzed in an effort to determine during which months of the following year less frequent sampling might be conducted. Sampling times would be selected so as to maximize their representation of critical physiological and environmental changes and in particular, of organism-environment relationships. The resultant Phase II sampling program would then proceed as a much more cost-effective method of gathering information.

2.2 Sensitivity of Long-Term Monitoring Programs

All ecosystems undergo long-term changes, some of which may be cyclic and others unidirectional. Some may be due to natural climatic variation, geological events, or biological processes; others to subtle, long-term anthropogenic influences. At present, few research strategies are available to determine which changes are cyclic and which are unidirectional or to distinguish anthropogenically induced changes from natural ones. These and other central ecological issues make clear the need for long-term quantitative data for both theoretical and practical purposes.

One of the major questions that must be answered by the Corps of Engineers is at what levels of effort and sensitivity must a long-term monitoring program be conducted? Without an answer to this basic question it is difficult to completely design a realistic long-term monitoring program. If the purpose of the sampling program is to detect only major perturbations in the ecosystem at widely separated stations in the bay, then the level of effort and sensitivity of sampling design would need to reflect this requirement.

The term sensitivity refers to the ability to detect change. Highly sensitive programs enable very subtle changes to be detected, and less sensitive programs detect only large or gross changes. In many cases, the degree of sample replication substantially contributes to the sensitivity of the sampling program. The replication data obtained for this pilot study is not adequate to determine the number of replicate samples to be analyzed for the long-term monitoring project, thus no recommendation may be made in that regard, until the completion of the recommended second pilot study.

Assuming the existence of sufficient estimates of variation, the degree of replication is best decided prior to the initiation of a monitoring project. At that time, the sensitivity of the program as a whole, and of each of its components can be selected.

If on the other hand there is a need to detect more subtle changes at fewer stations in the bay and to attempt to distinguish between natural fluctuations and those imposed by anthropogenic disturbance, a considerably increased effort would be required to conduct a more sensitive sampling program.

The authors of this report concur with the suggested approach for long-term ecological monitoring recently developed by the National Science Foundation (Conference Reports #1, 2, and 3). These reports emphasize that extreme care must be taken in the selection of methods for long-term study. The authors generally recommend that measurements should provide data to:

(1) Identify unidirectional and cyclic changes.

(2) Test ecological theories concerning stability, diversity, community structuring, and system development.

(3) Detect time lags in the ecosystem's response to outside influences.

(4) Act as sensitive indicators of ecological change.

They also recommend that measurement techniques should also have the following characteristics:

(1) Simplicity and reliability--so that studies made at different sites or times or by different investigators may be compared with confidence.

(2) Stability--that is, unlikely to change drastically over long periods or be subject to rigorous intercomparison when techniques change.

Estuaries provide a host of interesting problems and questions since they are characterized by rapid changes in many factors in the temporal and the spatial dimensions. Regular and irregular tidal oscillations, sporadic freshwater inputs and irregular wind stresses affect the salinity and turbidity. Plant nutrients come from many sources and the amounts available for phytoplankton may or may not be limiting. Rates of primary productivity and the dominant phytoplankton species vary widely in space and time. Dissolved oxygen may range from supersaturated near the surface to immeasurable levels at the bottom at the same time and station. These trends are affected by channel dredging, sediment resuspension, and waste discharge. Trace element and PCB availability and uptake rates are affected by the changing levels of nutrients, toxic materials and pathogens which may or may not be accumulating in the ecosystem. There are a large number of central questions implied by the above brief list of interacting factors. The qualitative relationships between some of these factors are generally understood, but the quantitative relationships are not, and are critical, basic ecological questions.

Levels of sensitivity must be selected only after consideration of costs. Therefore, it is essential to clearly establish the goals of a long-term monitoring program, the sensitivity of the sampling design, consistency of technique and the duration of the study. Any long-term monitoring program design must contend with the tremendous number of contributors to the variance of environmental parameters encountered in an estuary; yet a cost-effective program to meet the established goals must be created.

An attempt is made in this report, within the restrictions imposed by the paucity of appropriate data, and the lack of a knowledge of sensitivity required, to make recommendations pertinent to the design of a long-term monitoring program.

2.3 Sampling Parameters and Sampling Frequency

A summary of the sampling design is presented in Table 2-1.

I. Duration of Study - Three years separated into two Phases

Phase I - Intensive sampling for one year.
Phase II - Basic monitoring for two years.

II. Site Locations

Lower Delta - Port Chicago
Transitional Zone - Mare Island
Central San Francisco Bay - Treasure Island
South San Francisco Bay - (optional) Site in the area between San Mateo Bridge and Dumbarton Bridge

III. Sampling Parameters - See Table 2-1

2.3.1 Water Column

It is recommended that Phase I water column measurements of trace elements, PCBs and nonfilterable residue (NFR) be made monthly. Ammonia- and nitrate-nitrogen can be taken as background data. Measurements of salinity, temperature, turbidity and dissolved oxygen (D.O.) should be made monthly, or if possible, by automated, continuous samplers.

Phase II sampling could be conducted once every three months if, and only if the data obtained during Phase I indicated that such a reduced level of effort would not decrease monitoring sensitivity below

TABLE 2-1. SUGGESTED LONG-TERM MONITORING PROGRAM

Parameter	Phase I Sampling Frequency	Phase I Total # Samples	Phase II Sampling Frequency Per Year	Phase II Total # Samples Per Year
I. Water Column NFR, Trace Elements, Physical Measurements[1] (salinity, temperature, D.O., turbidity), Ammonia- and Nitrate-Nitrogen[2] and PCBs.	Monthly	12	every 3 months	4
II. Suspended Particulates PCBs, Trace Elements.[3]	Monthly	12	every 3 months	4
III. Settling Particulates[4] PCBs, Trace Elements.	2/year	2	2/year	2
IV. Sediment[5] PCBs, Trace Elements, Particle Size Analysis	2/year	2	2/year	2
V. Suspended Test Orgnisms Gonad index, Glycogen/lipid, Taurine/glycine, Dry weight tissue/shell volume, Trace elements, PCBs	Monthly[6]	15	every 2 months[7]	10
VI. Artificial Substrate[8]	--	--	--	--

[1] Long-term sites, automatic monitoring.
[2] Delete unless concerned with dredge spoil resuspension.
[3] Separation by particle size not required unless relationship to suspended organism uptake can be established.
[4] Sampled more frequently if sediment resuspension of concern.
[5] Once a year, benthic organisms could be collected by core.
[6] Sampled monthly plus 3 times during active reproductive periods.
[7] Includes addition of 4 extra samples during reproduction period.
[8] Delete unless more laboratory work performed.

previously established levels, as discussed above.

Composite sampling is recommended rather than the collection of discrete grab samples. Duration of composition might be for 24 hours or perhaps less at each station. This pilot study has shown that of the variables investigated, salinity is that with the most prominent relation to tidal flux.

2.3.2 Suspended Particulates

During Phase I, composite samples could be made for PCBs and trace elements. Analytical separation of water column particulates into artificial categories based on sedimentation characteristics need not be made unless relationships between particle retention and size-dependent particle selection by suspended test organisms exist. *Mytilus edulis* has been shown capable of filtering from suspension all particle size groups which were separated and analyzed during this pilot study.

Phase II sampling would be conducted at a reduced rate assuming it is shown during Phase I that a reduction of effort would not decrease the utility of the data obtained.

2.3.3 Settling Particulates

It is recommended that settling particulates be sampled twice a year (in Phase I and II). This decision is based upon the fact that the test organisms are suspension feeders and may remove some larger particles which are settling through the water column. If deposit feeders or suspension feeders living in clastic substrata were the test organism, then the settling particulates would be more important. If resuspension of materials at either the water/substratum interface or in deeper layers is considered a possibility near monitoring sites, then settling particulates should be sampled more frequently.

2.3.4 Sediments

The same recommendations are made for sediment sampling frequency as for settling particulates. Biannual samples would be taken throughout both Phase I and II. Trace elements, PCBs, and particle size analyses would be performed on these samples. Once a year, benthic organisms could be collected by core to verify any major change in sediment characteristics. An annual collection and enumeration of benthic infauna would be conducted to serve as adjunct data and as an aid to interpretation if significant changes were found in sediment characteristics.

2.3.5 Artificial Substrate

It is recommended that, until more field and laboratory work is completed, the artificial substrate not be used. This pilot study has shown that there are many variables in the growth patterns of epibiotic communities. Both plant and animal populations change in species composition, period of attachment, metabolism and pollutant uptake rates. Other sources of pollutants (for example, settling particulates, and water column) were observed to affect estimates of contaminant content of epibiotic species. Therefore, it was felt that this task should be deleted unless additional research is done to improve the design of the racks for this type of study. These design improvements might include vertical rather than horizontal substrate tubes, thereby reducing the surface available for the collection of settling particulates. Short sampling intervals could be investigated to possibly reduce the amount of contaminants built up in the glass substrate tubes.

2.3.6 Suspended Organisms

Presented in the Evaluation (Section 3) are a variety of possible variables associated with using suspended organisms to assess the levels of contaminants occurring in the San Francisco Bay and Delta regions. However, with a properly designed field and laboratory program, we believe that the use of such suspended organisms can provide a practical means of monitoring toxicity levels via either major long-term changes, or by acute short-term changes.

The selection of a single test organism that will function at a normal metabolic rate at all three locations within the bay/delta system is very difficult. *Corbicula fluminea* appears to be a feasible selection for freshwater locations where the salinity does not increase above 10 ppt for any length of time. *Mytilus edulis* survived very well in the Central Bay where salinities are high. It is the transitional zone at Mare Island that presents the greatest problems. *Corbicula* should do well at this site during the rainy season when salinity is low, but will not survive the high near-marine salinity that occurs during the summer months. Conversely, *Mytilus* will survive well during the summer months, but will probably function at a reduced metabolic rate during the rainy season when exposed to lower salinity. It may be possible to utilize both organisms during those periods of the year when they will survive and function best; use *Corbicula* during the rainy season, and *Mytilus* during the summer months - although this arrangement makes it difficult to compare results between organisms without extensive laboratory and field comparison. An alternative to the use of either of the aforementioned bivalves would be the use of *Macoma* sp. (no attached bivalves were seen at Mare Island Pier, obviating the use of native organisms).

It should be noted, however, that there are substantial difficulties in the maintenance of a population of infaunal organisms in clastic substrata for recurrent sampling and such organisms may not survive long suspended in the water column. By suspending both Corbicula and Mytilus at Mare Island during the proposed Phase I period and observing their survival over an entire year in conjunction with contaminant uptake and depuration data, a determination of which of the two organisms might best be sampled during any given month of the Phase II period could be made. Thus for example, it might be established that Corbicula would be more appropriately used during winter months, while Mytilus should be sampled during other seasons.

As with any other measurement technique, the use of biological entities as monitoring devices requires scrupulous care to avoid the production of artifactual data. In this regard it is essential that monitoring organisms function in a controlled manner - the most readily attainable and controllable being that of a physiological "steady-state." A steady-state requires the absence of environmental stressors and implies that an organism is fully acclimitized; it is therefore essential that monitoring organisms be permitted adequate time for acclimitization to ambient conditions before "time zero," "baseline," or "background" levels are measured. The same precautions clearly must be observed before attempting measurements which purportedly indicate responses to environmental conditions.

It is very likely that during this pilot study insufficient time was allowed for acclimitization by Mytilus and Corbicula. Examination of scientific literature in addition to the indication that test organisms were indeed stressed (see Section 2) suggests that periods of from 120 to 180 days may be necessary for physiological adjustments. M. edulis transplanted by the California Department of Fish and Game from Drake's Estero to Humboldt Bay were found 85 days following the transplant, to still be accumulating heavy metals from the new environment (Martin and Stephen, 1978) - that the mussels had not reached an equilibrium with their environment after almost three months is a clear demonstration that erroneous conclusions might easily be drawn from short-term studies.

Examination of trace elements in bivalve tissue replication data shows considerable variation among replicates; such variation likely is the result of the markedly different elemental burdens known to exist in bivalves, even within small local populations.

Adjustments of the sampling design to cope with high variation among individuals can be made only after a decision on the reason for sampling the test organisms is established. Thus, if only changes in part of a whole local population, with regard to contaminant burden are considered of importance, one might sample and combine many individuals (20 to

200 of the same size class) for each replicate analysis. These individual pooled field replicates, after tissue preparation, could be subsampled in the laboratory to provide error estimates for that portion of the measurement process. If, on the other hand, information regarding within population variance is sought, many small samples (five pooled individuals from the same size class) from within the populations of interest would be required. Analysis of individual organisms is limited by size and available tissue for low-level laboratory detection.

3. EVALUATION

3.1 Introduction

The data gathered for this study and the analysis of the data were designed to provide information to develop a long-term monitoring program for San Francisco Bay. No attempt was made to follow seasonal trends nor to analyze the data to provide additional, in-depth information on bay ecosystems. The major objectives of this study were to address the sampling design, station location evaluation, parameters to be tested, sampling methods, test organisms to be used, sampling intervals, analytical methods, study period and the control of variables in the field. This evaluation format is designed to address each of these major objectives based upon the literature and data obtained from this study.

3.2 Evaluation of Apparatus

The sampling design and apparatus employed for the acquisition of water column, bottom sediment, artificial substrate and test organism samples are presented in Section 5. The evaluation of apparatus used is presented below on a taskwise basis and is based upon the performance of this equipment in the field.

3.2.1 Water Column Polychlorinated Biphenyls (PCBs)

The field apparatus used for the collection of water column PCBs functioned well throughout the study and was free of mechanical failure. The in-line flowmeters and throttling valves located in the collection lines permitted precise regulation of water intake through each of the Slocum samplers. The results of preliminary experiments performed on the mechanical function of the device suggested that the flow rate of 650 mL/minute employed by Anderlini et al. (1975) was optimal. For these preliminary observations, transparent 2-inch I.D. glass cores were used so that observations of the polyurethane plugs could be made under various conditions of flow and suspended particulate density. It was observed that flow rates higher than 800 mL/minute tended to cause deformation of the plugs and channeling of the water would result. Under conditions of flow less than 450 mL/minute, channeling of the water was not observed; however, flow rates less than 450 mL/minute would require an excessive amount of time for collection, since samples were to be taken during the short tidal period of slack after ebb. As sampling proceeded, occasional minor adjustments of pump speed and throttle opening were required. This would occur as the foam plugs began to fill with particulates. In no instance did this prevent either the maintenance of specified flows or the balance of the flow through both of the samplers.

3.2.2 Suspended Particulate PCBs

The all stainless steel and glass apparatus used for the collection of water column PCBs (Section 5.1.1) was specially developed for obtaining these samples. The advantages of the negative pressure system are:

(1) Since the water sample contacted only prewashed metal and glass, the possibility of sample contamination by synthetic tubing and pump parts was minimal; and

(2) The flow rate employed for the collection of water column trace elements (1.2 m/second) could be matched by the negative pressure system for the collection of water column PCBs.

As noted in Section 5.1.4, the above flow rate allowed an unbiased collection of particles up to 80 microns in diameter.

3.2.3 Collection of Settling Particulates - Bottom Sediment

The PVC and stainless steel cores employed for the respective collections of settling particulate PCBs and trace elements are described in Section 5.1. The major advantage of sampling with these coring devices is that the need for more complicated alternative means (e.g., scuba divers) is eliminated. The design and composition of the coring apparatus (that is, the use of prewashed PVC core and check-valve for sample collections for trace elements) minimized the possibility of sample contamination. However, one disadvantage of this device is that the sediment (primarily silts) often slipped from the cores during recovery and required repeated attempts at sample collection. Also, it was difficult to evaluate if the volume of sediment and settling particulates collected was enough to insure accurate laboratory analysis and composition. However, modification of the check-valve type or core dimensions may alleviate this problem.

3.2.4 Suspension of Test Organisms and Artificial Substrate

The installation of and retrieval methods used for test organisms and attached macrofauna are described in Section 5.1.10. Generally, the test organism suspension system performed satisfactorily. No samples were lost during the study, but minor problems with line fouling occasionally occurred. The mesh size of the bags (1 mm) may have been too fine as sediment and algae began to clog the bags. For long-term monitoring, a larger mesh size should be employed.

Overcrowding of test organisms may be an important factor. This can be minimized by using a larger bag. In addition to using a larger size bag, the racks holding the bags might be suspended horizontally in the water column. In this manner, the organisms would not lie on top of one another.

Also, since water depth and tidal height ranges vary at different sampling sites, the racks might be suspended equal distances from the surface rather than at mid-depth. During summer months, the water column is typically stratified into several horizontal layers. By maintaining the test organisms at equal distances from the surface, the "layer" of water exposed to the organisms will be more standardized.

All artificial substrate (Section 5.1.11) racks were recovered, although occasional tube breakage did occur. This breakage may be unavoidable as racks are light and subject to damage by floating objects, extreme tidal current, or by impact against the pier pilings. The problem of damage can be minimized by the use of extra racks installed as a contingency, especially for long-term monitoring. The use of floating racks would reduce the chances of line fouling, damage caused by impact against the pier, and would keep the suspended organisms a set distance from the water surface.

3.2.5 Laboratory Precision and Sample Replication

For each type of analysis performed during this project, the collection-analysis procedure was replicated once. Thus, for example, during the first sampling effort at Mare Island, two sediment cores were collected and later analyzed. Data derived from these replicated efforts are presented in Section 7, Tables 7-1 through 7-12.

Evaluation of laboratory precision is most difficult with the limited data available. Examination of this data reveals that for some samples, no variance in replicate analyses was measured, whereas data from other samples varied considerably. This observation is also true for the same element measured in different types of samples. For example, the coefficient of variation for arsenic ranged from 0.0 for the smallest particle size in suspended particulates and the water column, to 56.57 in settling particulates. Since the same instrument was used to measure arsenic, regardless of sample type, the difference in the values of coefficient of variation must be largely a result of one or more of the following sources: (1) preparation of samples prior to analysis, (2) the sample collection, (3) transportation technique, or (4) variability among replicate samples. The data is not adequate to determine the various amounts of variation contributed by the individual sources.

The preceding explanation of variation illustrated by the trace element arsenic, was to exemplify the problems associated with the replicate data obtained for this pilot study. Similar differences of variance were seen in the remaining trace elements and other replicate sample data.

It is evident that a more detailed investigation of replicate analyses is warranted prior to commencing the long-term monitoring program. Therefore, a second pilot study is recommended. The details of this proposed sampling study are discussed in detail in Appendix B.

Another aspect requiring close examination is the reproducibility of sampling and laboratory methods. The settling particulates were collected by a coring device (Section 5.1.6). Using this method, there was very little control in the impact of the core on the sediment and the degree of agitation of the sediment/water sample during transport to the laboratory. Undoubtedly, the stronger the core impacts the sediment during collection, and the more sample agitations during transport, the more probability that settling particulates will become resuspended. Conversely, if no agitation of settled particulates occurred, then some of the suspended particulates may have time to settle prior to freezing (Section 5.1.4) in the laboratory. Should this method be used in the long-term monitoring project, it is recommended that the sample collection be standardized or an alternative device used, and the core samples be quick-frozen immediately after collection. This should minimize suspension or settling of the samples, and therefore the results will more truly represent the actual field conditions.

The suspended particulates for trace element and PCB analysis were collected using a peristaltic pumping system (Section 5.1.4. and 5.1.5). A total of four 14-Liter carboys were filled with water; two carboys for trace element analysis, and two carboys for PCB analysis. All carboys were filled within the same 30-minute intervals. It was observed that visibly different amounts of sediment were collected in the carboys. Such marked visual differences suggest small scale heterogenicity in the water column and therefore that considerable replication may be necessary to achieve data with which subtle changes may be detected.

3.3 Station Location Evaluation

The problems associated with sampling during this pilot study at the three sampling sites are discussed below. From this discussion, station selection criteria have been developed.

As presented in Section 5, three military harbor facilities were pre-selected for the sampling sites: Mare Island, Port Chicago, and Treasure Island. The Treasure Island site was chosen as an alternative location due to problems encountered at Berkeley Pier, the original central bay sampling location.

The Berkeley Pier is accessible to the public 24 hours a day. At Mare Island and Port Chicago, the retrieval lines for the suspended bivalve and artificial substrate racks were secured to the pier and left for the duration of the sampling program. In an attempt to avoid vandalism of these racks at the Berkeley Pier, the racks were attached to a section of the pier accessible only by vessel. However, on two separate occasions, suspended racks of bivalves placed for acclimation prior to sampling, were lost due to vandalism. This delayed the scheduled sampling by several weeks. In addition, the use of a vessel to collect the suspended bivalves and artificial substrate racks is dependent on weather and bay conditions. As encountered, the weather and bay conditions may be unsatisfactory for collecting the suspended racks, yet at the same time, be satisfactory for water and sediment collection from the pier.

Since the sampling design was time-contingent, it was felt that after several weeks' delay due to vandalism, and the problems associated with collection of the suspended racks by vessel, an alternative Central Bay sampling site should be found. The lack of sampling problems at the military installations suggested Treasure Island as the alternative sampling site.

A possible pollutant source when sampling from piers are moored vessels and nearby vessel traffic. This could be a potential source of trace metal and PCB input creating high levels in the samples (see Section 4.3) due to resuspension of sediment and settling particulates by propeller wash, exhaust discharge into the water column, and possible fuel spillage. At Mare Island, a decommissioned icebreaker was moored at the sampling pier for the entire duration of the study; during the first 24-hour sampling effort, the Chester Harding was conducting dredging operations in the immediate proximity of the sampling site. This operation may have had an effect upon some of the parameters sampled, especially suspended particulates. At Port Chicago, tugboats would occasionally enter and leave the nearby pier. At Treasure Island, a potential source of bottom sediment BCB could be the result of a large electrical transformer that fell through the pier in 1970. It was removed five years later in 1975. Such transformers typically have considerable amounts of oil in them. Submerged obstructions at the Treasure Island pier prevented sediment collection from the immediate area of water column and test organism collection sites.

There were, however, major advantages from sampling off these piers. Since these piers were restricted areas, the suspended racks of test organisms and artificial substrate remained undisturbed during the sampling interval. Sampling could occur in nearly any type of weather, day or night. There was enough space on these piers so that all sampling equipment could be set up on location prior to the collection of water. In this manner, all sampling occurred in the shortest time possible. With the exception of the suspended particulates collection (70 minutes due to a fixed pumping rate and the required time to collect 40 Liters of water), collection of all water samples during routine sampling took less than one hour.

From previous discussions on problems associated with sampling, plus general observations made during collections, station selection criteria have been developed. These criteria concentrate on the selection of the specific sampling site once the type of water mass to be sampled has been selected.

The following list of criteria may be considered optional. We realize that no such sampling site may exist which satisfies all the listed considerations. Therefore, the relative importance of each consideration must be viewed in respect to the overall goals of the project. Certain "tradeoffs" between site location and possible problems inherently associated with each site location will most likely have to be made.

3.3.1 Site Selection Criteria

1. Sampling platform - piers. Although a number of technical and logistic difficulties are presented by the use of pier sites for monitoring projects of this type, pier site locations are recommended over other alternatives. A possible alternative to piers is the use of a vessel. A vessel provides the capabilities of sampling almost anywhere; however, there are several disadvantages. A vessel of considerable size would be required to accommodate the sampling gear used in this project and to retrieve the racks. For a project of any duration, expense could be a prohibitive factor, as vessel time and personnel are costly. Use of a vessel can be weather-dependent with poor weather conditions disrupting the sampling frequency. If suspended racks of test organisms or artificial substrates are a part of the project, then they ought to be placed in the same area where the rest of the samples are taken. This too, presents a variety of problems. Racks must be clearly marked for relocation and navigation and cannot be placed in shipping channels. Vandalism due to accessibility by other vessels is a concern as is the damage to markers and racks caused by floating objects. Therefore, it is recommended that for this type of long-term project, pier sites be used.

2. Restriction of public access. As previously discussed, a major problem encountered with the Berkeley Pier was vandalism. Not only did vandalism substantially delay sampling at the Central Bay site location, but entire sets of data can be easily lost throughout the sampling interval. It is therefore recommended that the site location be restricted from public access. At the three sampling sites used for this study (Mare Island, Port Chicago and Treasure Island), public access was not a problem.

3. A pier site location without moored vessels or heavy vessel traffic might be selected. This is an inherent problem when sampling from piers. This may or may not be a critical consideration for future projects. However, the problems associated with vandalism are considered to be more pertinent to site location selection than those associated with nearby moored vessels or vessel traffic near the sampling pier.

4. Ample working space. A considerable amount of pier working space was required not only to set up the various collection devices, but also to separate the suspended racks of test organisms and artificial substrate tubes. This was not a problem at the three sampling locations used for this project.

5. Lack of submerged objects. Submerged objects at Treasure Island prevented the sediment core samples from being collected at the same place that the water samples and suspended racks were collected.

6. The occurance of native attached macrofauna on the sampling pier may be advantageous. In this manner, transplanted test organisms may be directly compared to the native populations.

7. The investigation of any submerged objects which may be a potential source of contaminants is important. For example, at Treasure Island, a large electrical transformer was submerged under the pier. Such transformers typically have substantial amounts of cooling oils, thereby contributing PCBs to the sediment and/or water column.

8. Investigate any recent or potential spillage of oil, gasoline, paint, or other chemicals. To our knowledge, such spillage did not occur at any of the sampling site locations in this study.

9. Examination of local current. Very strong currents or turbulent water may inhibit the use of suspended racks of test organisms. No difficulties along these lines were encountered during this project.

10. Longevity of sampling site. A sampling site location should be chosen where potential long-term sampling can occur from the same facility, uninterrupted.

11. Data from any historical sampling programs at or near a sampling site should be compiled. Such information may play an important role in selection of sampling sites.

12. The sampling site should, to the highest degree possible, truly represent the water mass which is to be studied. This should consider tidal influence, water circulation and water depth.

These considerations are not listed by order of importance. As previously mentioned, the overall goals of future projects should determine the relative importance of each criterion.

3.3.2 Establishment of a Permanent Site Network (National Program)

If long-term sites are established for monitoring in San Francisco Bay it is strongly recommended that the program follow the guidelines now being established by the National Science Foundation (Conferences #1, 2 and 3). If the San Francisco sites could become part of the National Network much additional data could be obtained. Weather data (sunshine, rainfall, wind velocity), tidal cycle information and standard physical factors (temperature, salinity, D.O., turbidity) are monitored automatically. Then the other parameters addressed by this pilot study could also be taken at each station on a regular basis. The establishment of permanent sites for long-term ecological data is badly needed for San Francisco Bay. With permanent sites and automatic sampling equipment for the routine monitoring of parameters, the results from more specialized sampling can be better described and relationships to cyclic and unidirectional trends followed.

3.4 Relationships of Environmental Parameters and Tidal Cycles

A variety of water column samples were measured at hourly intervals throughout one complete tidal cycle in order to determine the variation of these parameters with tides. These parameters included dissolved oxygen, salinity, temperature, turbidity, nitrate-nitrogen, ammonia-nitrogen, nonfilterable residue, settleable solids, and tidal height. This data is presented in Appendix A and data analysis in Section 7.2.

Three sampling locations were preselected for study: Treasure Island in central San Francisco Bay, Mare Island at the Carquinez Strait and Port Chicago in the Suisun Bay. The salinity regime, measured during a complete tidal cycle at each station, clearly reflects differences in physical environments among these sampling locations. Treasure Island is indicative of a near-marine environment with salinities averaging 26.6 ppt. The freshwater influence from the Delta was minimal at this station. Port Chicago reflects a near-freshwater environment with salinity being near zero. At both of these stations,

salinity remained relatively constant throughout the tidal cycles. At Mare Island, however, salinity was closely associated with the tidal curve; salinity increased during flood tides and decreased during ebb tides with values ranging from 3.5 to 13.0 ppt.

It should be noted that the salinity regimes were measured during the rainy season when freshwater runoff from the upper San Joaquin-Sacramento Delta is the greatest. During summer months, marine water intrudes into Suisun Bay due to the lack of freshwater runoff. This saltwater intrusion is kept out of the Delta by releases of fresh water from upstream reservoirs in the Sacramento River (Kelly, 1966). During the summer months, salinities are typically higher at each of these stations. At Port Chicago, salinities are typically highest in late summer (8 to 10 ppt) (Kelly, 1966). Preliminary data from U.S. Geological Survey (USGS) indicated salinities between 26 to 27 ppt at the Carquinez Bridge and 30.6 ppt at Yerba Buena Island in August 1978. Thus, considerable seasonal variation in regard to salinity occurs at both Port Chicago and Mare Island.

Examination of the data obtained by the 24-hour sampling revealed that the highest levels of parameters did not occur at the same sampling location. For those water quality parameters measured hourly during one complete tidal cycle, Port Chicago had the highest mean concentration of the following water quality parameters: D.O., nitrate-nitrogen and turbidity. Mean values of nonfilterable residue and ammonia-nitrogen were highest at Mare Island, and salinity was highest at Treasure Island. Values of settleable solids were routinely below the laboratory detection limits.

Examination of the data presented in this study indicates that no clear relationships of these water quality parameters measured were observed with respect to tidal cycles. The "value" of measuring settleable solids may be minimal since nearly all of these values were below laboratory detection limits. The degree of fluctuation of the remaining parameters was not consistent between stations, indicating relatively discrete environmental conditions at each sampling location. It should be noted that hourly sampling throughout a complete tidal cycle was conducted for only one of the four sampling efforts at each site. The remaining samples were collected at slack tide after ebb. Since there was a lack of association with these water quality parameters and tidal cycle, there is no evidence from this data that the subsequent samples collected at slack tide reflect the "worst" or "best" possible conditions during the tidal cycle in which the sampling occurred.

It should be noted that sampling throughout a tidal cycle at each station was conducted during wet weather conditions. It is possible that during the dry weather season, a variety of relationships between

these water quality parameters and the tidal cycles may occur. Also, if such relationships do exist in wet or dry weather conditions, several consecutive tidal cycles may have to be sampled hourly in order to reliably detect and describe them.

Whether or not hourly sampling of a tidal cycle should occur in future studies is contingent on the rationale for obtaining such information. If the purpose is to obtain a value to indicate a representative levels of these water quality parameters over a tidal cycle, then composited hourly samples may suffice. If composite sampling were to be conducted, then differences in levels of the parameters within the tidal cycle will not be measured. If, however information regarding variations within tidal cycles is sought then discrete samples, taken periodically within tidal cycles, are required.

When considering tidal cycle sampling frequency, the type of parameter to be sampled should be considered. For example, the data presented in Section 5.2 reveals wide changes (depending upon sampling location) throughout the tidal cycle in values of nonfilterable residue, turbidity, and salinity. Whereas levels of ammonia- and nitrate-nitrogen were, for the most part comparatively less variable throughout the tidal cycles. Therefore, depending on the information to be obtained, it may be possible to specify the frequency of collection for different parameters for the purpose of maximizing sensitivity and minimizing cost of collection and analysis. Such a cost-effective sampling program can be obtained if a careful selection of parameters to be measured is made; and the methodology of sample collection (composite v. discrete) and frequency of sample collection, reflects the degree of information to be obtained as well as the overall "sensitivity" of the data for analysis.

3.5 Artificial Substrate

The use of the in situ Aufwuch sampler works well for determining growth rate and population dynamics. The use of a photosynthetic index (photosynthesis/Chlorophyll a) has been used very successfully by Horne (1974) to quantify the impact of discharges on the growth rate of the Aufwuch communities. However, when this platform is placed in the field, a large number of variables are present if trace element and PCB values are measured. The species composition changes over time. Particulate material containing trace metals and organics settle on the racks and organisms. If no organisms attached to the roughened glass rods, trace metals and organics could still be detected from the influence of the water column and settling particulates. Therefore, this method does not seem to be a good one to determine the pollutant uptake rates or levels of microfauna and microflora. Without additional laboratory and field testing, the data from this pilot study indicates that this sampling task method should not be used for long-term monitoring.

3.6 Applicability of the Test Organisms

The use of attached or suspended macrofaunal organisms to detect various contaminants in the environment has been applied in Europe and used in bays and open water in this country. The use of caged organisms suspended from racks in San Francisco Bay has been used by the Corps of Engineers, State (Calif.) Water Quality Control Board and some selected domestic sewage discharge districts. It is too early in the program for some of the longer term results to be completed from the State projects. However, the United States and World Wide Mussel Watch has been developed to monitor selected pollutants along the coasts of some parts of the world. Preliminary results from the California mussel watch have demonstrated the usefulness of attached macrofauna as monitoring organisms.

San Francisco Bay represents true estuary conditions with year-round Delta inflow. The influx of fresh water into the system produces a wide range of changing factors as pointed out earlier in the discussion. This fact makes the selection of a single organism which can withstand the salinity range from freshwater to marine conditions without affecting survival, metabolism rates and uptake values very difficult. If sampling sites were to be established in the lower Delta, transitional areas Mid-Bay, and South Bay, most likely three species would be needed - *Corbicula fluminea* for fresh water, *Mytilus edulis* and *C. fluminea* at the transitional zone, *M. edulis* at the mid-bay point, and perhaps *Musculus senhousia* or *Ischadium demissum* for the south bay area. The preliminary results of this study show that both *Corbicula fluminea* and *Mytilus edulis* seem to be suitable as test organisms in the areas in which they were suspended. Mare Island presents the greatest problems since no single species tested would live under ideal conditions for the whole year.

3.6.1 Station-by-Station Comparison

As was stated earlier, the stations established for this study represent the extremes of estuary conditions; Port Chicago as fresh water, Mare Island as a transitional point and Treasure Island as Mid-Bay with marine conditions. Therefore, each station is quite different and the organisms selected must be able to respond to the changing conditions not only between stations but over time at each station. One of the prime factors between stations and within stations is salinity.

3.6.2 Salinity

Kinne (1964) and Remane & Schlieper (1971) have reviewed the information on the relationship of salinity to the general physiology of marine invertebrates. *Mytilus edulis* is considered to be euryhaline and has an extremely wide salinity tolerance ranging from 4 to 5 ppt in the Baltic to full marine conditions. Bayne, Thompson & Widdows (1976) indicate the necessity for very careful consideration of the time/course of the metabolic adaptations to change in salinity. When the respiration rates of mussels from a range of environments have been measured at their extremes (5 to 6 ppt), intermediate (15 ppt), and marine (30 ppt), the rates remain similar. However, when mussels are experimentally exposed to altered salinity over a short period, the rate of oxygen consumption is higher in the salinity to which the animals were accustomed in nature (Bouxin, 1931). Theede (1963) found that immediately after transfer to above or below ambient salinities, the filtration rate by *M. edulis* was reduced. After 7 to 10 days, this reduction was diminished, but in extreme salinity differences the rate never returned to the levels of the control.

The *Mytilus edulis* collected from Point Richmond and used as transplant stock were collected in a salinity of 20 ppt in February 1979. The mean salinity range at Mare Island was 8.9 ppt (3.5 to 13 ppt). Therefore, the mussels had to acclimate to a salinity decrease of 7 ppt to 12 ppt. The period of acclimation to a lower salinity most likely far exceeds the 2-week time required for temperature acclimation (BØhle, 1972). In fact, the glycogen/lipid data indicate that the animals were under stress during the whole period of the pilot study. Schlieper (1955) has suggested four to seven weeks for complete compensation depending upon temperature. Our results indicate a longer period of time may be necessary.

Corbicula fluminea was collected in fresh water and transplanted to Mare Island with a salinity increase of 8 to 12 ppt. Laboratory tests conducted during the pilot study indicate that *C. fluminea* may have difficulty withstanding salinities above 10 ppt for prolonged periods. Metabolic rates were reduced in *Corbicula* in salinities above 10 ppt (see Sections 7.9 and 7.10). Larger *Corbicula* did not survive at either Port Chicago or Mare Island and yet those animals placed in laboratory tanks have survived for six months in fresh water. The reason for the low survival of larger specimens in the environment has not been determined. A recent survey by the University of California at Davis has found that only the smaller *Corbicula* occur in the lower reaches of the Delta (Knight, 1979).

3.6.3 Physiological State

Bayne (1975) defines stress: "Stress is a measurable alteration of a physiological (or behavioral, biochemical or cytological) steady-state which is induced by an environmental change and which renders the individual (or the population or the community) more vulnerable to further environmental change." It is important in uptake studies of transplanted organisms to describe the "condition" of individual animals at any point in time and to be able to establish the time when transported organisms have reached some steady-state condition. As was pointed out in the previous section the physiological state and acclimation periods resulting from salinity changes are important but only relate to this one variable; whereas there are many more in estuary conditions. The physiological state affects pumping rates, feeding efficiency, survival, reproduction, and general metabolism. The uptake of pollutants is also related to the physiological conditions of the organism and the period of acclimation. For example, *M. edulis* acclimates to change in temperature by altering its feeding and respiration rates to maintain scope for growth (Bayne, 1976). This rate change could also affect uptake of contaminant levels over time.

Based on the results from this study (four individuals sampled), the use of a gonad index established from an increased sampling of 20 individuals monthly and related to glycogen/lipid, taurine/glycine ratios will give a reasonable idea of physiological state. Additional indices could be used, such as the proportion of the internal shell volume which is occupied by the body tissues (Baird, 1966) correlated to glycogen level in the tissues. Carbon-to-nitrogen ratio has also been used as an index of condition by Ansell and Sivadas (1973). The gonad index would not necessarily have to be sampled over more than one year. Once the relationship between reproductive state (or some other measure of physiological activity) and glycogen/lipid and taurine/glycine ratios have been established for the test organism, the continued monitoring of the gonad development would not be necessary.

In order for a condition of stress to be established, some disadvantage must be shown from a decline in physiological state of the animal. The results of the field study indicate that the recommended index used in this pilot study be applied as a major means of determining the physiological state of the transplanted organisms. During the first part of the long-term monitoring project, controls in native populations should also be sampled to correlate the natural physiological state with that of the transplanted organisms. As Bayne (1976) has pointed out, "The need for quantitative estimates of physiological condition in pollution studies would benefit from the deployment of quantitative estimates of the degree of stress in a population."

This statement is particularly important in uptake studies using transplanted organisms in areas that they are not normally found. There is a need for additional research on the development of the indices, and understanding of the conditions which affect the physiological state for a series of useful test organisms.

3.6.4 Uptake of Contaminants

Although rates of uptake may be related to the external concentrations, there is no certainty that concentrations in the organism will reflect those of the environment (Bryan, 1976). Some species are able to excrete a higher proportion of the metal intake under contaminated conditions, and thereby regulate the concentration in the body at a steady-state level.

There is evidence that mollusca can absorb heavy metals from solution. Bevelander and Nakahara (1966), showed that pinocytosis occurred in the absorption of colloidal gold by the mantle cells of bivalve molluscs. Cadmium was absorbed in *Mytilus edulis* (Fowlers and Benayoun, 1974), and chromate in *Tapes desussatus* (Chipman, 1966). There is no evidence that any animal can prevent the entry of metals by changing the permeability rapidly, although organisms such as bivalve molluscs can temporarily prevent absorption by closing the shell (Bryan, 1976).

As far as bivalves are concerned, in the majority of cases, food and particulates are a much more important source of metals than the water. However, most of the evidence concerns fairly large animals and was obtained with the aid of radioisotopes under normal, rather than metal-contaminated conditions (Bryan, 1976). Therefore, it may be dangerous to state at this time that the bivalve uptake in this study is retaining trace elements and PCBs solely from the suspended particulates.

A large amount of data exists on the excretion and regulation of heavy metals in marine and freshwater organisms. Aside from possible loss by diffusion, various systems for losing metals have been recognized in molluscs. These include excretion as granules from the kidney of scallops, excretion in spheres pinched off from the digestive cells in *Cardium edulis*, and the storing and ejecting of material by leucocytes (Bryan, 1973; Owen, 1955; Galtsoff, 1964; Youge, 1926). The metabolism of metals would affect the level of detectability (tissue levels) as it relates to the pollution sources. This fact may have been involved with the decrease of copper from 40 ppm in *M. edulis* collected at Point Richmond in mid-February, to 13 ppm (in late June) for the transplanted *M. edulis* at Treasure Island. Levels of many trace elements in the native mussels at Treasure Island were not significantly different from the levels in transplanted mussels after

60 days. Both the transplanted and native mussels at Treasure Island had significantly lower levels of copper as compared to the mussels at Point Richmond. Although there is not enough information to be certain that the metal was excreted, the information does suggest that regulation is a strong possibility. M. edulis transplanted to Tomales Bay from the Selby Pier during a 24-day desorption study showed that arsenic, cadmium, copper, mercury, nickel, lead and zinc levels decreased (Anderlini et al., 1975). Schulz-Baldes (1974) calculated that to reach an equilibrium in lead concentration in Mytilus edulis, it would take 230 days. This pilot study was not designed to determine rates of equilibrium of either trace elements or pollutants. However, it is an important factor to keep in mind when interpreting uptake information in transplanted organisms over short periods of time.

One author (Boyden, 1974) has shown that the concentration factor for a metal often depends on the animal's size; in Mytilus it was shown that concentrations of lead, copper, zinc and iron fell with an increase in weight, while levels of nickel and cadmium remained constant. This pilot study did not address the relationship of animal size to uptake levels since only one size class was analyzed for both Mytilus and Corbicula. However, the tissue from other size classes was preserved, and this question could be addressed at a later time. Studies of Macoma balthica showed that the lowest salinities and highest metal concentrations resulted in the greatest metal accumulations (Anderlini et al., 1975). These results most likely reflect the complex relationship between physical factors (salinity, temperature), chemical factors (trace elements) and the physiological state (metabolism, excretion and regulation).

Trace element concentrations can also affect respiration rate, and thus metabolism and eventually uptake of the trace elements themselves (Brown and Newell, 1972). The depression of respiration rates may be brought about by inhibiting ovary activity as well as by direct metabolic inhibition.

3.6.5 Practical Problems

The results of this pilot study indicate that the use of attached or suspended organisms can serve as a useful tool if sufficient background information is developed for each best species used. In addition to the variables discussed earlier, there are some practical problems which should be addressed.

The number of individuals necessary for any one station for a one-year period can rapidly mount. Enough organisms should be transplanted at the beginning of the project so that the study can proceed for at least one year without transplanting additional organisms. Since

there is little information on the mortality of suspended organisms in the San Francisco Bay and the Delta, sufficient individuals would have to be used to compensate for mortality during the study. The present pilot study indicates that with the exception of some metals, more replicate field samples of suspended organisms would have to be taken during each sampling period so subtle differences can be significantly detected. During the first year of the study, suspended organisms should be sampled monthly. If five size classes are used per station, this could amount to 266 individuals per month, or in the case of Mytilus, 3,200 individuals per year. If only two size classes are used, it would reduce the number to about 116 per month or 1,440 per year. These figures include 20 individuals for a gonad index, and pooled chemical analysis, and a 20 percent mortality rate. During this pilot study, substantial supplies of readily available mussels were difficult to find. Mussels in public access areas are heavily collected for bait and human consumption. Likewise, Corbicula is nearly absent from areas in the Delta where it has been commonly collected; great numbers are used for bait and some are shipped overseas for human consumption. To import Mytilus edulis from areas like Tomales Bay would introduce additional variables, including a different genetic population acclimated to a higher, more stable salinity regime.

This practical problem is not easily solved, although some solutions could be suggested. There are abundant supplies of mussels attached to protected piers and jetties (under the control of Navy or Coast Guard agencies) which could supply the needs of the study for a number of years. Mussels are easily raised and San Francisco Bay stock could be raised in unpolluted conditions, maintaining the genetic makeup and then transplanting them in San Francisco Bay in the F_1 or F_2 generations. This alternative is much more expensive than using adult, native mussels from the Bay, but has the added feature of providing mussels of known pollutant background levels. These levels would be much lower than the native level and the mussels could be raised at the salinity concentration encountered at the study stations. This factor would reduce time needed for acclimation to salinity conditions at the stations.

An arrangement could be made with the State of California, Department of Water Resources, to obtain Corbicula from one of the canals in the Central Valley where they are considered a nuisance. Background levels of pollutants would be low and a large supply could be obtained.

The design of the suspension racks should be changed. A floating structure attached to the pier would suspend the organisms at a uniform distance from the surface and orient them to the same current direction. This type of rack would be easier to maintain, and would facilitate collection of the Nytex bags. The use of the Nytex bags can be recommended, although fewer organisms should be placed in each bag than the number of organisms per bag used during this pilot study.

The technique of stitching parallel seams along doubled-over margins proved successful in preventing any bags from splitting open. Melting the bag edges to fuse them was tried, but was not successful. The suspension of the bags on the racks worked well, and the same type of rack construction could be used on a floating support by simply setting the racks in rows on the platform below the water level in a central well.

This discussion brings to light the many complex factors which interact between the environment and organisms. On one hand, the complexities of an ever changing estuary with wide physical and chemical fluctuations presents real challenges for sampling desings. On the other hand, the complex reaction to these changes by attached or suspended organisms provides a whole different set of variables. In spite of their tendency to close their valves and undergo long periods of acclimation after exposure to pollutants and/or environmental change, bivalves will continue to be used as indicator organisms. They are good composite samplers which, over long periods, will provide a stable database since they do not react to short duration change unless it is severe. Therefore, despite the difficulties in using bivalves as test organisms, valuable long-term data can be obtained. In order to make this long-term data more valuable, additional work should be accomplished. This would include study of the extent of byssal attachment, growth and condition measurements, larval development and various physiological indices of stress. Future studies should use these indices for assessing the effects of pollutants such as organohalides, various trace elements and the possible synergistic and antagonistic effects of the mixture of different pollutants.

In addition, for selected test species in San Francisco Bay, work should be completed that would include studies of metabolism, excretion, and regulation - as well as rates of uptake of various pollutants. The recommended sampling programs suggested in this pilot report reflect the need for long-term studies concurrent with discrete laboratory and field work to answer some of the questions posed by this pilot study and the literature.

PART II

METHODS, MATERIALS & RESULTS

4. STUDY AREAS

According to the U.S. Army Corps of Engineers' (Corps of Engineers) "Scope of Services" dated May 19, 1978, the pilot study was to be performed at three stations located within the San Francisco Bay/Sacramento Delta region. Initially, the sites specified were to be in the Central Bay (Berkeley), Carquinez Strait (Mare Island), and Suisun Bay (not specified). Following consultation with the Corps of Engineers' representatives, a sampling location at Port Chicago was chosen as the Suisun Bay site. The specific sampling site at Port Chicago was located at the U.S. Navy Barge Pier (Figure 4-1). The Mare Island sampling site was located on the southern portion of the island at the U.S. Coast Guard Pier (Figure 4-2). The original site chosen for sampling of the Central Bay was the Berkeley Pier. This pier is open to the public and is a preferred location for sport fishing. Also, a considerable volume of small boat traffic is characteristic of this area. The use of the Berkeley Pier as a sampling site proved unsuccessful. There were two major problems associated with sampling at the Berkeley Pier, weather and vandalism. A detailed discussion of these problems is presented in Section 3.3. Treasure Island was selected as a satisfactory alternate sampling site for the central bay, shown in Figure 4-3. A detailed description of each sampling site follows.

4.1 Mare Island

As noted above, the sampling for the pilot study was performed on the Coast Guard Pier at Mare Island. All samples for water column and sediment evaluations were collected from the end of the pier. The bivalve and Aufwuch racks were also installed at the end of the pier. Representative water depths encountered during sampling and height of the pier from the surface of the water are illustrated in Figure 4-4. Public access to the pier is totally restricted and the appropriate security clearances had to be obtained from the Navy prior to each sampling effort. Use of the pier facilities is restricted to the Coast Guard. A number of characteristics of the pier and observations made during the sampling efforts may have some relevance to the data collected in terms of artifact introduction. These observations are discussed below.

A decommissioned icebreaker was docked on the eastern side of the pier and was present throughout the study. A Coast Guard rescue vessel was located on the western side of the pier; this vessel was frequently used, and was observed to leave and return to the dock during all four sampling efforts. The path of travel of this vessel included an area within 20 yards of the site from which samples were collected.

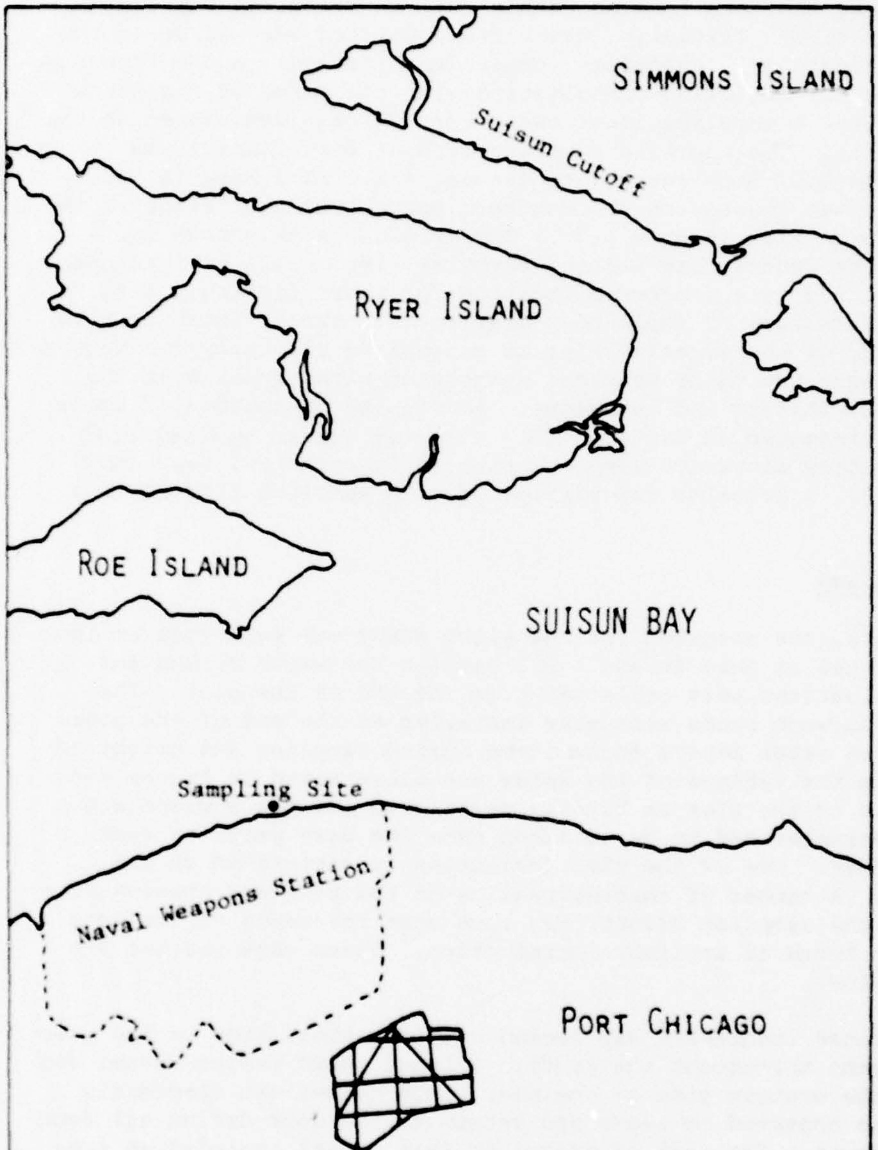


FIGURE 4-1 . SUISUN BAY SAMPLING LOCATION, NAVAL WEAPONS STATION (Port Chicago Site)

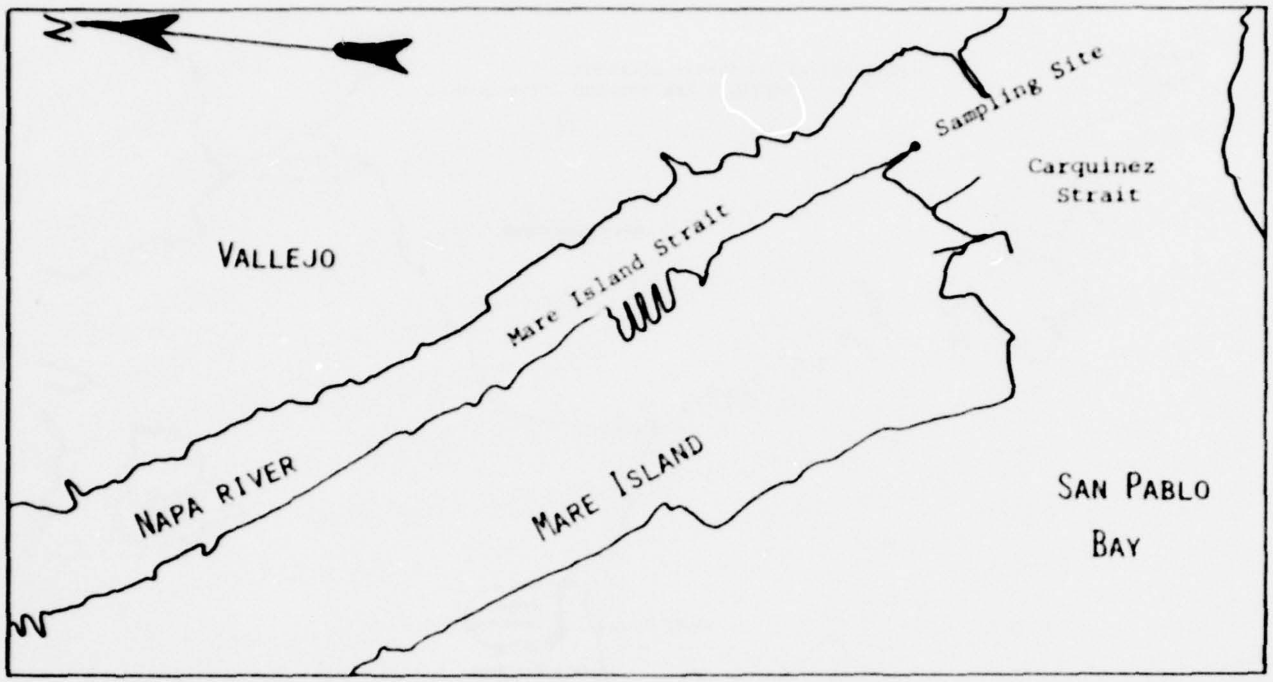


FIGURE 4-2 . CARQUINEZ STRAIT SAMPLING LOCATION (Mare Island Site)

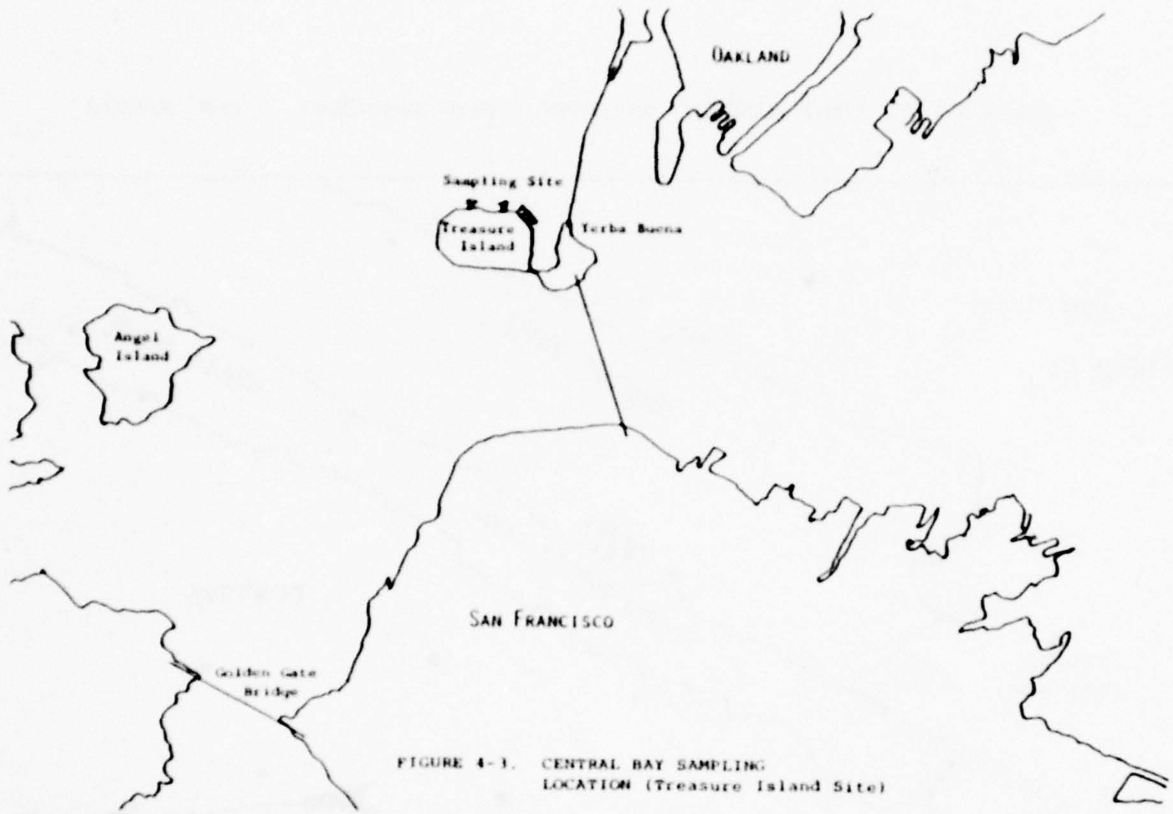


FIGURE 4-3. CENTRAL BAY SAMPLING LOCATION (Treasure Island Site)

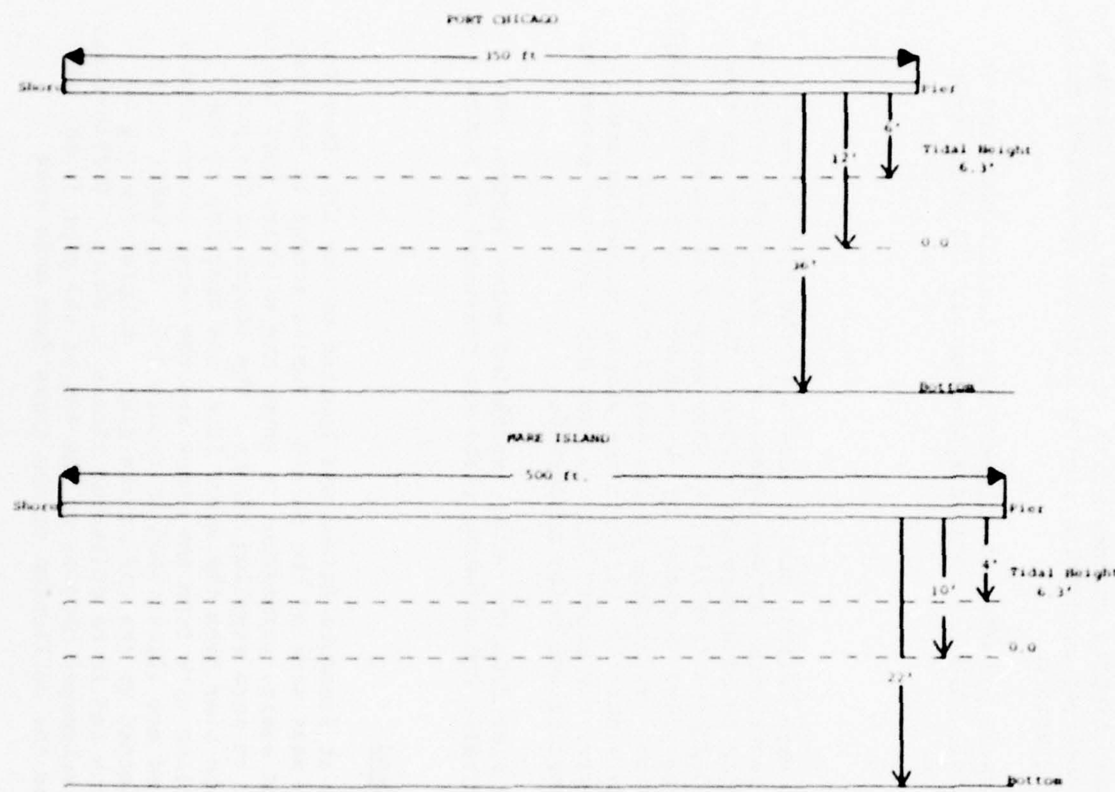


FIGURE 4-4. WATER DEPTHS ENCOUNTERED

During the 24-hour sampling effort, the hopper-dredge Chester Harding made hourly passes in close proximity to the pier. The ship was conducting a dredging operation in the Napa River and was discharging the spoils into the shipping channel south of the pier. The Chester Harding was also observed conducting similar dredging operations during the second sampling effort.

There was considerable private and military boat traffic observed in the shipping channel, which is located approximately 100 yards from the end of the pier.

4.2 Port Chicago

As is the case at Mare Island, public access to the Port Chicago Military Base is restricted; it was necessary to obtain permission to enter the base prior to each sampling effort. The sampling for the pilot study was conducted from the U.S. Navy Barge Pier located adjacent to the tug pier. A number of vessels were moored in proximity to the sampling site, but because of its restricted location, no vessels could pass within 100 yards of the sample collection area. On occasion, however, the moored Navy tugboat did leave and return to its pier while sampling was being conducted.

The height of the pier from the water, estimated water depths, and location of the bivalve and Aufwuchs racks are presented in Figure 4-4.

4.3 Treasure Island

The sampling site at Treasure Island was located on the U.S. Navy Fuel Pier (#15) on the east side of the island. Public access to the pier was restricted and again, permission to enter the military base had to be obtained prior to each sampling effort. The length of the pier, the distance of the pier from the water line, the distance of the water column sampling site from the shore and the water column depths at the area sampled are illustrated in Figure 4-5. All water column samples were collected at the end of the pier. Samples for the evaluation of sediments had to be collected closer to shore. Difficulties encountered with submerged objects at the end of the pier (rocks and pilings) prevented the collection of the cores from this area.

Vessel traffic in the immediate vicinity of the sampling site was observed to be light. A pair of mooring dolphins located immediately in front of the pier prevented vessels from maneuvering close to the pier. Only a single vessel was observed to use the pier for mooring purposes. This Navy Fuel Barge was moored on the east side of the pier during the second through the fourth sampling efforts.

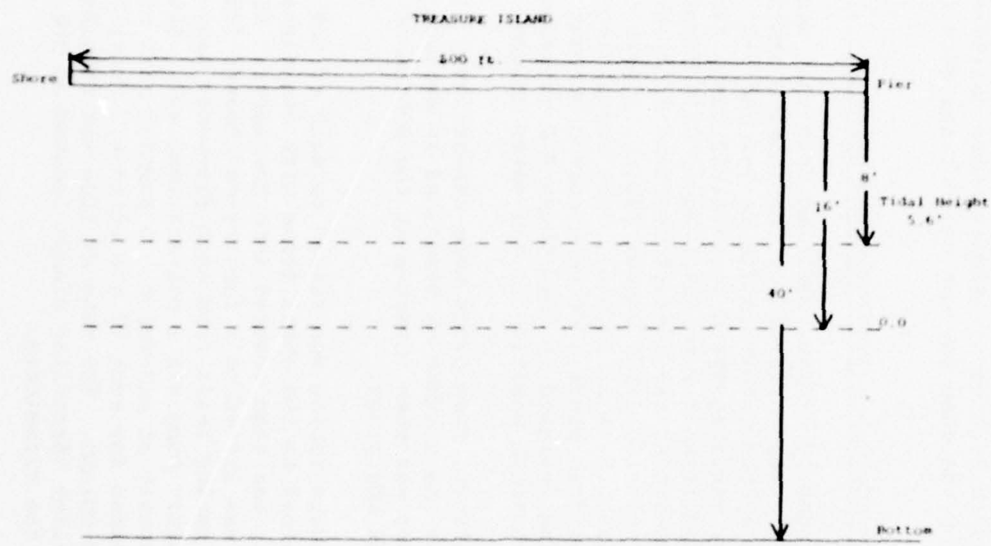


FIGURE 4-5. WATER DEPTHS ENCOUNTERED (Treasure Island Site)

5. METHODS AND MATERIALS

5.1 Field Collection Methods

The methodology of the field collections for each of the tasks specified in the Corps of Engineers' Scope of Services dated May 19, 1978 is described below. These tasks and the various dates and sites of collection are summarized in Section 6. Samples were delivered to the laboratory for analysis on the same day the collections were made.

5.1.1 Collection of Water Column Polychlorinated Biphenyls (PCBs)

A specially constructed pumping system, modified from that described by Anderlini et al. (1975), was employed for the in situ extraction of water column PCBs. This system, shown in Figure 5-1 and 5-2, consisted of a high-capacity variable-speed peristaltic pump, capable of delivering volumes ranging from 74.9 to 454 L/hour (Cole Parmer #7549-19), a gas-powered AC generator, two 20-foot sections of 5/16-inch I.D. flexible polyvinyl chloride (PVC) vacuum tubing, a pair of stainless steel columns (2-inch O.D. x 20 inches), each containing five high-density polyurethane foam plugs (706 cc combined volume) and a ½-inch steel support frame designed to hold these PCB extractors ("Slocum" samplers) in vertical position in the water column.

Prior to each sampling effort, foam plugs were exhaustively extracted and loaded into the columns as described in Section 5.2.2. A stainless steel retainer was then inserted at the bottom of each column to prevent loss of the plugs.

At the sampling site, vacuum tubing was fitted to each of the columns which in turn, were attached to the steel frame with stainless steel hose clamps; the assembly was then lowered into the water. Vacuum tubing from each column was fitted to a factory-calibrated flowmeter (Gilmont #F-1500). PVC tubing leads from each flowmeter were then connected to the peristaltic pump via a polyethylene wye. Samples were collected simultaneously at mid-depth. A pumping rate of 620 mL/minute was maintained for each of the columns. Forty liters were passed through each column. The rate of flow was regulated and balanced by means of in-line throttling clamps located on the upstream side of the pump behind the flowmeters.

Approximately 70 minutes were required for sample collection. Sample volume was monitored by collecting the water in calibrated collection vessels as it was expelled from the system. Each collection effort included the slack after-ebb tidal stage. Upon completion of sampling, Slocum samplers were wrapped in aluminum foil and returned to the laboratory.

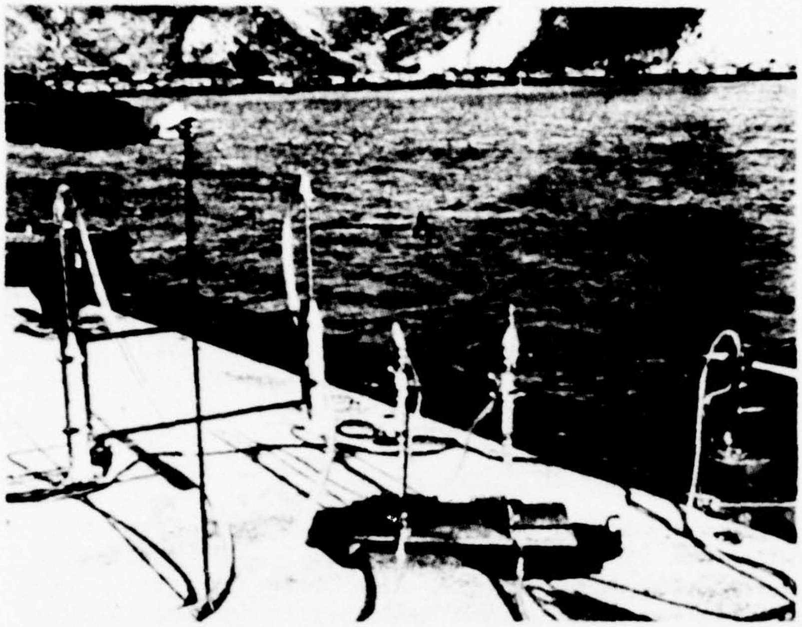


Fig. 5-1. Water column PCB extraction apparatus
A=PCB(Slocum)Sampler, B=Flowmeter, C=Throttle

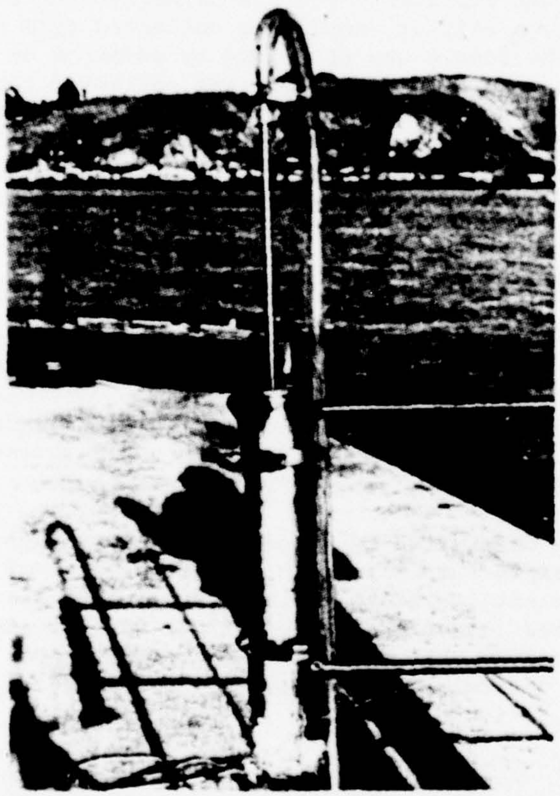


Fig. 5-2. PCB (Slocum) Sampler

5.1.2 Collection of Water Column Trace Elements

Collection of water for the determination of dissolved trace elements was accomplished using a peristaltic pump and a 6.1-meter section of flexible PVC tubing. The tubing was attached to the exterior of a 9.1-meter section of 2-inch diameter schedule 40 PVC rigid pipe; the assembly was then lowered into the water column to mid-depth. The sample was collected in a 250 mL acid-leached teflon bottle and subsequently preserved with 5 mL concentrated, redistilled nitric acid.

5.1.3 Collection of Additional Water Column Data

In addition to the collections made for PCBs and trace elements, in situ determinations of dissolved oxygen (D.O.), salinity, and temperature were made and water samples were collected for the laboratory determination of nitrate- and ammonia-nitrogen, settleable and nonfilterable solids, and for turbidity. Measurements of D.O. and temperature were made with a YSI Model 57 oxygen meter; salinity was determined using a YSI Model 33 SCT meter. Prior to sampling, the oxygen and and SCT meters were calibrated using titrimetric methods (Standard Methods, 14th Edition). For the determination of ammonia- and nitrate-nitrogen, a 2-liter sample was collected from mid-depth by peristaltic pump. The sample was preserved by addition of 2 mL concentrated sulfuric acid. A second sample was collected for measurement of settleable and nonfilterable solids; this sample was not chemically preserved. A 40 mL sample for turbidity was collected and preserved with 0.1 mL of a 40 g/L mercuric chloride solution. All samples were stored at $4^{\circ}C$ until delivered to the laboratory.

5.1.4 Collection of Suspended Particulates - Trace Elements

Collection of water and suspended particulates was accomplished using a peristaltic pump, a 6.1-meter length of 5/16-inch flexible PVC tubing, and a 14-liter hard glass (Kimax) carboy. Water was collected in the same manner as that for determination of dissolved trace elements (Section 5.1.2, above); it was pumped directly into the carboy at an intake velocity of 1.2 m/second from mid-depth.

The pumping rate was determined by assuming a specific gravity of 2.65 for particulates in suspension; an intake velocity of 1.2 m/second then would be sufficient to ensure collection of particles up to 80 microns in diameter (Anderlini et al., 1975; Shelley and Kirkpatrick, 1973). The flow rate was optimized before sample collection was begun; rate was determined as it was during collection of water column PCBs.

5.1.5 Collection of Suspended Particulates - Samples for PCB Analysis

A negative pressure pumping system constructed of stainless steel and glass was designed specifically for the collection of suspended particulate PCBs. This system, shown in Figure 5-3 consisted of the peristaltic pump operated as a vacuum source, an assortment of 1/4-inch I.D. stainless steel tubing lengths fitted with 5/16-inch socket-weld threaded fittings (Type 316, Duhig & Co., Inc.), and a specially-machined vessel plug fabricated from soft steel. Prior to sampling, tubing sections were assembled to the length required and attached to the plug. The plug was inserted into the carboy and a seal between the plug and carboy effected by use of a neoprene "O" ring fitted to the exterior of the plug.

The pump was attached to a vacuum-tight fitting on the plug. The carboy was evacuated and the resultant pressure differential (nominally, 0.97 kg/cm^2) was sufficient to draw water into the carboy. By regulation of the pump speed, flow velocity was adjusted to 1.2 m/second. Thus the water sample contacted only pre-washed steel and glass. Two 14-liter carboys were filled in this manner. Following collection, carboys were covered with aluminum foil and transported to the laboratory.

5.1.6 Settling Particulates - Trace Elements

Two PVC cores (2½ inches I.D. x 22 inches long) were used to collect samples containing settling particulates. The apparatus used, shown assembled in Figure 5-4 consisted of the PVC cores, a polypropylene check valve, and various lengths of threaded pipe. The check valve was attached to the top of the core; sections of pipe sufficient in length to reach the sediment/substratum were then attached to the top of the check valve, and the assembly pushed through the water and into the substratum. As the core was removed from the sediment, closure of the valve caused retention of the sediment core and overlying water. The cores were then stoppered and taken to the laboratory. Care was taken not to disturb the sediment during transport.

5.1.7 Settling Particulates - PCBs

Two stainless steel cores, a 2-inch I.D. brass check valve, and sections of pipe were used to collect samples for settling particulate PCBs (Figure 5-4). The procedure used for collection of settling particulates for trace element determinations was also used to obtain samples for settling particulate PCB evaluation, except that steel cores, rather than PVC cores were used. Cores containing samples were brought to the surface, stoppered, stored upright, and transported to the laboratory.

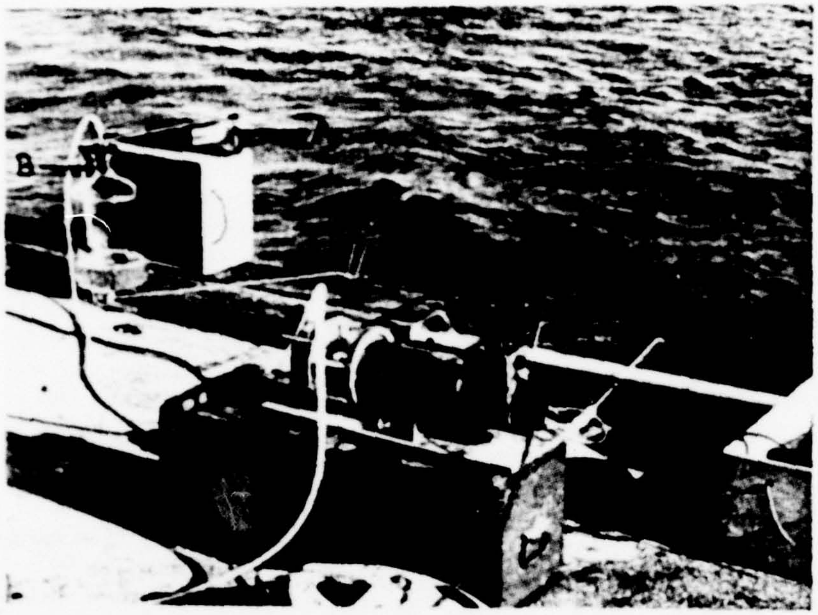


Fig. 5-3. Collection apparatus for suspended particulate PCB. A=Stainless steel tubing, B=Stainless steel plug, C=Vacuum source.

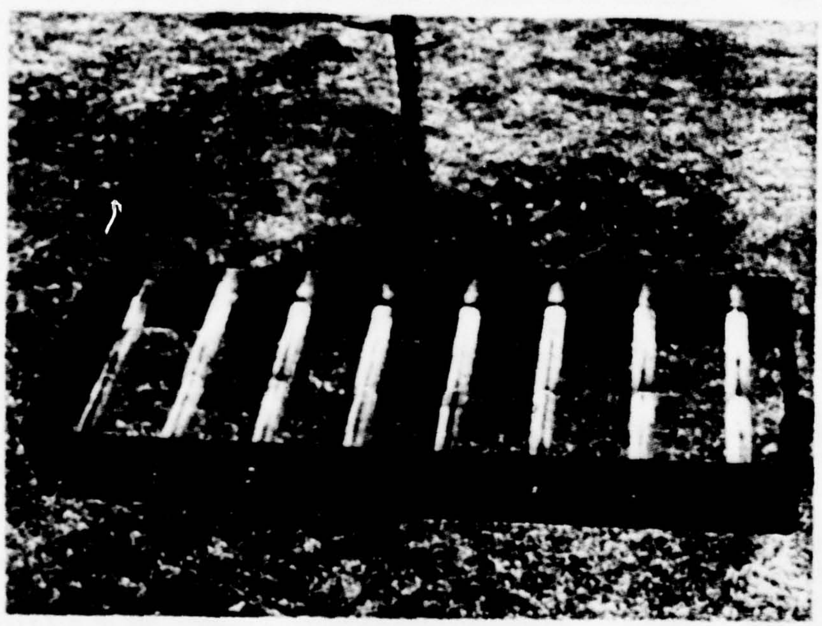


Fig. 5-7. Stainless steel artificial substrate racks.

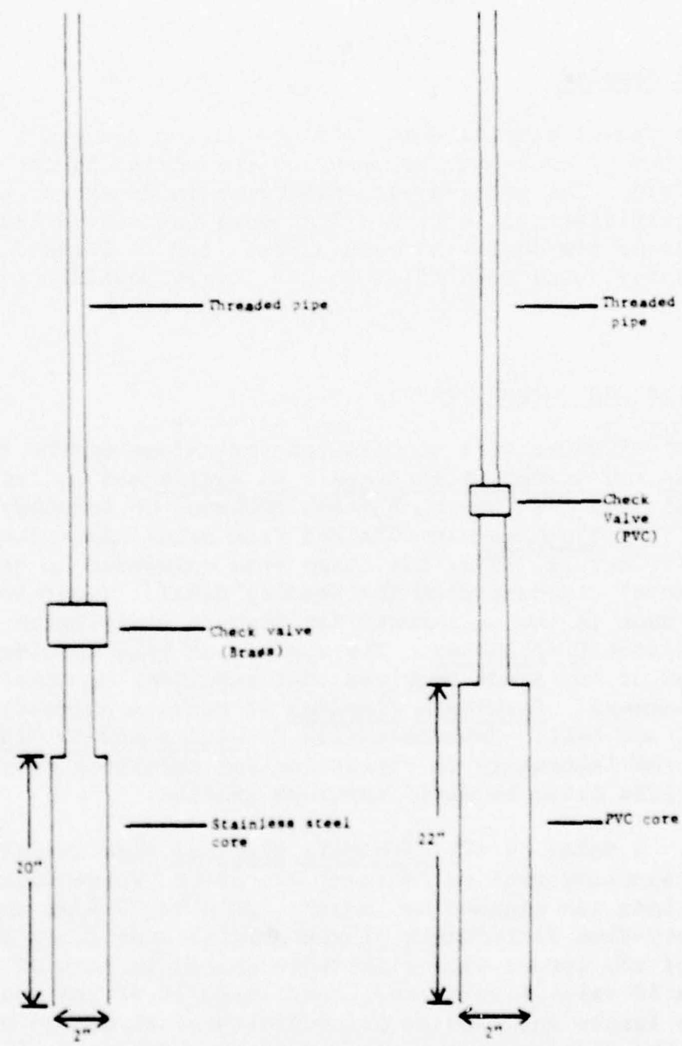


FIGURE 5-4. COLLECTION APPARATUS FOR SETTLING PARTICULATES

5.1.8 Sediment Samples for Particle Size Analysis

Sediment for particle size analysis was obtained using the coring procedure described in the previous section. The analysis was performed by wet-sieving the sediment sample through Tyler sieves of the following mesh sizes: 0.600, 0.425, 0.250, 0.180, 0.125, 0.075 and 0.063 micrometers. The results are presented as percent and cumulative percent weight per size category.

5.1.9 Faunal Samples

Two replicate faunal samples were obtained during the first and last sampling efforts at each site by means of the coring device described in Section 5.1.6. The samples were preserved in 5-percent buffered formalin shortly after collection. Each core was sieved through faunal screens of the following mesh sizes: 1.0, 0.5 and 0.25 mm. The fauna retained were identified to the lowest possible taxon and counted.

5.1.10 Bivalve Test Organisms

Two species of bivalves were used as test organisms in the field, *Mytilus edulis* and *Corbicula fluminea*. *M. edulis* was collected from the intertidal zone just north of Point Richmond on February 12, 1979 (Figure 5-5). *C. fluminea* was obtained from Bales' Bait Shop in Antioch on February 12, 1979; the clams were collected on the previous day by commercial clammers from the Mendota Canal. Separate sampling efforts were made in the Sacramento/San Joaquin River Delta in an attempt to collect *C. fluminea*. The absence of this species and the short duration of the study required that specimens be obtained from commercial clammers. *Corbicula fluminea* is heavily harvested, for both food and bait. Representative *M. edulis* and *C. fluminea* were delivered to the laboratory to obtain initial reference data on trace elements and PCBs prior to field exposure studies.

Port Chicago. A total of 475 *Corbicula fluminea* were installed at the Port Chicago sampling site on February 20, 1979. These individuals were divided into two classes by length: 20.0 to 39.9 mm and 40.0 to 65.0 mm. Sixty-five individuals of the smaller size class and 35 individuals of the larger size class were placed in each of four Nytex bags (15 cm x 50 cm). A fifth bag, containing 50 of the smaller clams and 25 of the larger was used as protection against damage or loss of the others. The five bags were secured on a wooden rack (0.7 m x 1 m) which in turn was fixed to a 3/8-inch nylon line and suspended in the water at mid-depth. A 45 kg cement anchor was used to hold the racks in place. A pulley threaded with polypropylene line was attached to each anchor prior to installation. A bivalve-suspension rack was

FIGURE 5-5. COLLECTION SITE OF Mytilus edulis TEST ORGANISMS

attached to one leg of the line and the other leg tied off to a cleat secured to the pier (Figure 5-6). Recovery of the rack was accomplished by retrieving the line on one side of the weight. During each of the four sampling efforts one bag was removed; the rack and remaining organisms were then resuspended.

Treasure Island. Five hundred *Mytilus edulis* were placed at the Treasure Island sampling site on April 11, 1979. To acclimate the test organisms for a similar length of time as was done for Mare Island and Port Chicago (as mentioned in Section 3.3), an additional one-month delay in sampling would occur. It was therefore decided to place the organisms in the field during the first water quality sampling effort, and to make the final collection of these test organisms sometime after the final collection of water quality samples. A 15-day interval between the final collection of water quality samples and test organisms was the longest time interval allowable in order to complete the project in accordance with contract specifications.

The mussels were cleaned of epibiotic growth and divided into four size classes viz. less than 45.0, 45.0 to 59.9, 60.0 to 69.9 and greater than or equal to 70.00 mm. Twenty-five mussels each, from the largest and smallest classes, a total of 50, were put into a 15 x 50 mm Nytex bag; 25 representatives from each of the two middling classes were put into a second bag. Five such sets of bags were suspended, one set to be removed for laboratory analysis at each of the four sampling dates, and the fifth to be used in the event of loss or damage to any of the others. The method of suspension and retrieval was as described above for *C. fluminea*.

Mare Island. At the Mare Island sampling site, both *M. edulis* and *C. fluminea* were used. The number of individuals, size classes, collection and details of suspension were as described above for *M. edulis* and *C. fluminea* at Treasure Island and Port Chicago sites, respectively. Bags of these species were suspended from the same line with *M. edulis* in the lower third of the water column and *C. fluminea* in the upper third. Three racks, initially installed on February 12, 1979, contained two bags of *M. edulis* and one bag of *C. fluminea*. After each sampling effort, three to five individuals of both *M. edulis* and *C. fluminea* from each size class were preserved in Bouin's Fixative for subsequent histological sectioning to determine gonadal state.

5.1.11 Artificial Substrate (Aufwuch)

Artificial substrate racks were identical in design to those described by Horne (1974). Four racks were installed at each of the three sampling sites during the first sampling effort. Two of the racks

were fabricated from stainless steel, the other two racks were made of plexiglass. All racks measured 40.6 x 14 x 6.4 cm and each held a total of 16 roughened glass tubes or "substrate units." The tubes (2½-inch x ½-inch I.D.) were suspended on eight rods (stainless steel or PVC, respectively, for metal or plastic racks). The racks with substrate units are pictured in Figures 5-7 and 5-8. Prior to installation at the sampling sites, the assembled units were prewashed as described in Section 5.2 to remove contaminants. The method of suspension and retrieval of these racks was the same as that used for bivalve racks as described above. Polypropylene line was used to retain plastic racks while stainless steel line was used with metallic racks. All were suspended at mid-depth. One plastic and one metal rack were removed during each of the third and fourth sampling efforts for analysis.

5.2 Laboratory Analysis

5.2.1 Water and Trace Elements

Water to be analyzed for trace elements was collected in Teflon bottles which had been leached in the laboratory. Leaching was accomplished by filling unused bottles to approximately 90 percent capacity with 50-percent (nominal, v/v), redistilled nitric acid and heating for a minimum of 24 hours at 44°C. Bottles were subsequently emptied, air-dried, and stored in polyethylene containers until used by field crews. Prior to sampling, approximately five milliliters of redistilled nitric acid (50% v/v) were added to each bottle.

Samples were stored at 4°C for a period of approximately 12 hours prior to filtration. To remove particulate material, the sample was passed through an acid-rinsed cellulose acetate filter of 0.22-micron nominal pore diameter. Following filtration, acidified samples were heated to approximately 70°C in Teflon containers and maintained at that temperature for a minimum of twelve hours.

All elements were subsequently determined by atomic absorption spectrometry with a Perkin-Elmer Model 370 (double-beam) spectrometer, Model HGA 2200 graphite furnace, and hydride and cold-vapor sampling systems. All determinations were made with deuterium-arc background correction.

Mercury was determined following generation of the cold (elemental) vapor by absorption at 253.7 nm (APHA, 1975). Arsenic and selenium were determined in an argon-hydrogen flame after purging from the sample as their respective volatile hydrides (U.S. EPA, 1974). Cadmium, chromium, copper, lead, and nickel were chelated with

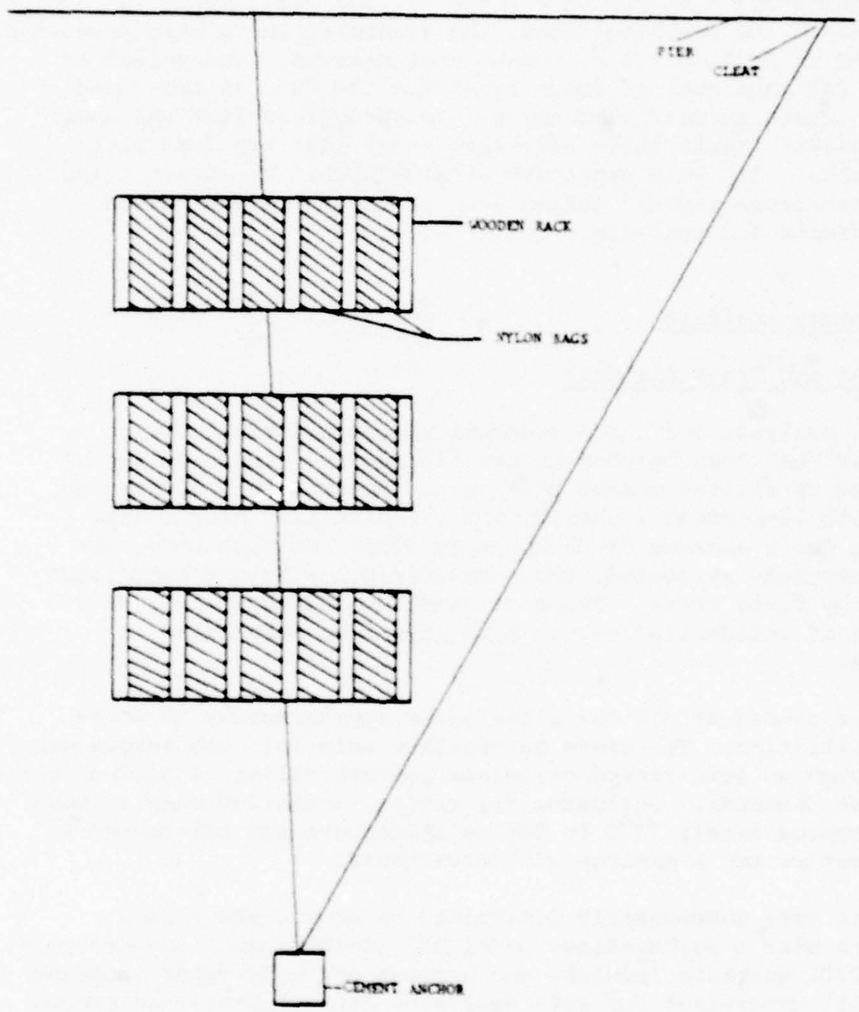


FIGURE 5-4. SUSPENSION APPARATUS FOR BIVALVE TEST ORGANISMS

Fig. 5-8. Plexiglass artificial substrate racks.

ammonium pyrrolidine dithiocarbonate (APDC), the chelate extracted into glass-distilled methyl isobutyl ketone, and subsequent determinations made by injecting microliter aliquots of the organic phase into the graphite furnace.

Labware used in trace element determinations was cleaned scrupulously prior to the initiation of each batch of analyses. Cleaning was always begun with a normal tap water/detergent (Alconox) washing. After several tap water rinses, a minimum of three rinses were made with ASTM Type III reagent water. Following this rinsing, labware was covered, air-dried, and stored. Prior to use, labware was rinsed with warmed, redistilled 50% v/v nitric acid and then at least three times with ASTM Type I reagent water. Type I water was produced by passing all-glass distilled water through two mixed-bed ion exchangers, a carbon-absorption filter and a 0.22-micron membrane filter (Milli Q System, Millipore Corp.).

5.2.2 Analysis of Polychlorinated Biphenyls (PCBs)

PCBs were extracted from water by using a "Slocum" sampler, slightly modified from that described by Risebrough et al. (1976). Polyurethane foam plugs in a combined volume of 706 cubic centimeters were extracted before use with hexane/acetone (1 + 1), distilled in glass (Burdick & Jackson, Inc.), in a Soxhlet extractor. Plugs were loaded into the stainless steel sampler contacting only stainless steel and aluminum in the process. Samplers were generally prepared no more than one day before use and openings were kept covered with aluminum to prevent airborne contamination.

On return to the laboratory, plugs were extracted by refluxing with hexane/acetone in Soxhlet apparatus. The extract was reduced with a rotary evaporator and a stream of high-purity nitrogen. The reduced extracts were cleaned up by passage through an activated Florisil column. Quantification was accomplished by electron-capture gas-liquid chromatography (EC-GLC) using a 183 cm x 4 mm glass column packed with 3% OV-1 and Chromosorb HP. GLC analyses were performed under supervision of Adeline Dreesman, Stoner Laboratories, Inc.

5.2.3 Suspended Particulates

Fourteen-liter Kimax carboys were used to contain samples from which suspended particulates were to be extracted. Two were rinsed after washing with 50-percent redistilled nitric acid and two were rinsed with glass-distilled acetone. The two pairs held samples to be analyzed for trace elements and PCBs, respectively.

Particulates were removed from samples by continuous-flow centrifugation as follows: prior to operation, the system was rinsed with a solvent (acid or acetone) appropriate for the analysis to be performed (trace elements or PCBs) on sedimented particles; the continuously-agitated sample was pumped by peristaltic pump at a predetermined velocity through a Beckman JCF/Z continuous-flow rotor with low-volume core in a Beckman JBZ-21 centrifuge; each sample was pumped through the rotor three times, and during each pass, pumping rate and rotor speed were adjusted to sediment particles of different equivalent spherical diameters. Thus, during "Pass A", at 500 rpm and 750 mL/minute, particles of equivalent diameters greater than or equal to 4 microns were sedimented; during "Pass B" at 1970 rpm and 750 mL/minute, particles between 1 micron and 4 microns were removed; and during "Pass C", 20,000 rpm and 400 mL/minute, particles of equivalent diameters between 1 micron and 0.07 microns were removed (Anderlini et al., 1975).

Particulates were washed from core cups with Type I reagent water and centrifuged in appropriately cleaned glass tubes or bottles, supernatant decanted, the sediment resuspended and the process repeated. The resulting sediment slurry was dried in a tared glass container and weighed. Residue to be analyzed for trace elements was wetted with Type I water and gently heated with concentrated nitric acid for approximately 24 hours. The digestate was made to volume and elements determined by atomic absorption. Residue to be analyzed for PCB content was extracted with acetone/hexane, extracts reduced and PCBs partitioned into petroleum ether. PCBs were determined by EC-GLC as described above.

5.2.4 Settling Particulates

Benthic sediments and settling particulate samples were collected simultaneously by coring as described elsewhere. Polyvinylchloride (PVC) cores were washed and rinsed with 50 percent (V/V) nitric acid and their contents used for trace element analysis. All stainless steel cores were rinsed several times with glass-distilled acetone before each use and their contents taken for PCB analyses.

On receipt at the laboratory, cores were frozen to -10°C. To obtain a sample, a core circumference was thawed sufficiently to allow extrusion of the sediment-interface-overlying water sample it contained. The interface of most samples was readily discernible as a brownish banding at the base of the frozen water column. A 4-centimeter section centered coincidentally with the interface band, was cut from each core and analyzed as a settling particulate sample. Analytical procedures, including digestion, and determination were as described above for suspended particulate analysis.

5.2.5 Sediments

A subsample of the extruded frozen benthic sediment to be analyzed for trace elements or PCBs was cut from the core used for settling particulates with its center 6 centimeters from the substratum/water interface. The freezing-extrusion process used in laboratory sampling of settling particulates accomplished several functions simultaneously. Freezing is an adequate method of preservation for samples containing nitrogenous and mercurial compounds because it effectively stops the microbiological activity that might otherwise alter recoveries of those substances. The relatively quick freezing of sediment/interface/water cores also served to retain particles in their respective matrices (water column, interface, or sediment) until sectioning and analysis. Frozen cores could easily be extruded, and the sediment/water interface located without ambiguity. Before field work was begun, consideration was given to the use of resuspension of settled particulates as a laboratory sampling technique. It is frequently observed that particle size (and therefore settling velocity) and contaminant burdens are related; if a resuspension technique were used, the size distribution of sampled particles, and therefore the contaminant data obtained, would to a great extent be a function not of field conditions, but instead of the particulars of the resuspension technique. Additionally, radical shifts in trace element distributions are known to occur as a result of increased exposure to elemental oxygen (Kalil and Goldhaber, 1973); suspension by agitation likely would have caused alterations in elemental distributions.

While freezing and thawing may well have slightly altered trace element speciation within, for example, interfacial particulates or sediments, such changes would not be detectable by methods used during this study because trace element data was gathered only for total burden, and not for individual speciated classes. Perturbations of samples which would cause migration of elements between sediment, interfacial particulates and overlying water could affect data substantially. Quick cooling and freezing, it was felt, would minimize and soon halt changes of that sort.

The rigorous digestion process outlined in 5.2.3 (Suspended Particulates) was used to liberate trace elements both loosely (e.g., exchangeable, organic) and tightly (e.g., mineralized) bound in the sediment matrix. It was expected that liberation of elements might be somewhat incomplete from the residual phase (Engler et al., 1977), though the refractory nature of such compounds prevents their acting as important sources in elemental exchanges. While description of elemental distributions is possible through varying digestion and extraction procedures, the limited scope of the present study precluded such involved procedures.

5.2.6 Bivalve Test Organisms

Mytilus edulis and *Corbicula fluminea* were analyzed for trace elements and PCBs. In preparation of samples for trace element analyses, five individuals were cleaned, shucked, pooled, and ground to a slurry in an acid-rinsed Waring blender with stainless steel blades. Each group of pooled mussels was homogenized over a five-minute period. Two aliquots of slurry were removed, one for determination of mercury and the other for determination of all other trace elements. That portion removed for the determination of mercury was digested at 45°C in 40 milliliters of concentrated sulfuric acid until clear. After cooling, 15 mL of 6% (v/v) potassium permanganate were added and the digestate analyzed by cold vapor atomic absorption.

The second aliquot, removed for analysis of other elements, was digested in acid-washed Erlenmeyer flasks with 90% (v/v) nitric acid. Digestion was considered to be complete when the solution cleared or turned to an apparently stable pale yellow. Digestates were made to volume with Type I water and elements determined by atomic absorption spectrometry.

For the determinations of lipid and glycogen, five mussels or clams were selected and homogenized in 2:1 chloroform:methanol for not less than five minutes. The resulting phases were allowed to separate and aliquots transferred to tared glass ampules. The solvent was removed under a partial vacuum with the aid of a gentle stream of nitrogen. Net residue was taken as lipid. Defatted residue was air-dried at 80°C and a weighed portion digested in 30% (w/v) sodium hydroxide at 100°C. Cooled digestate was neutralized and then diluted with ASTM Type I water. Glycogen was determined as glucose after reaction with 0.2% (w/v) anthrone in 95% (v/v) sulfuric acid (see Seifter et al., 1950).

5.2.7 General Chemical and Physical Water Quality Parameters

General chemical and physical water quality parameters were estimated using standard analytical methods. Temperature, salinity and dissolved oxygen were measured in situ with YSI field instruments. Settleable solids were determined with an Imhoff cone at room temperature (22°C), which is the standard test temperature for settleable solids. Non-filterable residue was determined following filtration through Whatman GF/C circles and drying at 105°C.

Ammonia was distilled from borate-buffered samples and determined by nesslerization. Nitrate was quantified using the brucine method and turbidity was determined by nephelometry with a Turner Model III fluorometer. All colorimetry was performed with a Beckman Model 24 spectrometer, a double-beam instrument, using 1.000 cm and 5.000 cm path lengths.

5.2.8 Artificial Substrate

Racks to be suspended as collectors of settling biota (see Section 5.1) were cleaned in the laboratory prior to being taken to the field. Steel racks, and the roughened glass tubes they retained, were rinsed twice with reagent water and covered with aluminum foil for transport. Rigid acrylic racks with their roughened tubes were washed with reagent nitric acid before placement in the field. Individual volatile solids determinations were made on one to three glass tubes; the number used was determined by examining the density of attached organisms and estimating the number of tubes necessary to achieve detectable weight loss. Tubes were dried at $105^{\circ}C$, weighed and ignited at $550^{\circ}C$ for two hours. Net difference between dried and ignited tubes was taken as volatile solids.

For determination of Chlorophyll a and total organic carbon, tubes were ground in a stainless steel mill. A portion of the resultant powder was extracted with occasional stirring in the dark at $4^{\circ}C$ for 24 hours. Chlorophyll a was determined spectrophotometrically at 663 nm (with a maximum bandpass of 2 nm). Positive interference due to the presence of pheophyton was eliminated arithmetically.

Organic carbon was determined on a portion of pulverized settling tube after oxidation under pressure (15 p.s.i.g.) in an acid-persulfate medium. The resulting carbon dioxide was determined by infrared absorption on an Oceanography International Carbon Analyzer. Data are expressed as μg C per tube.

Portions of pulverized tubes to be used for trace element determinations (other than mercury) were digested in 90% (v/v) nitric acid, made to volume with the ASTM Type I reagent water and individual elements determined as described above. Weighed fractions were also removed for determination of mercury by cold-vapor AAS. Details of digestion are as described for preparation of suspended particulates. PCBs were removed from pulverized tubes by refluxing in hexane:acetone in a Soxhlet extractor. Solvent volume was reduced by rotary evaporation. PCBs were quantified by EC-GLC as described above.

The free amino acids, taurine and glycine were extracted from Mytilus edulis and Corbicula fluminea tissues by homogenizing pooled whole bodies in fresh, glass-distilled water. Aliquots of homogenate were removed, centrifuged in Corex bottles to a compact pellet and the supernatant withdrawn. The pellet was resuspended, the suspension spun again, and the resulting supernatant added to the first.

Protein was allowed to precipitate overnight following the addition of 95% ethanol. Extracted amino acids were separated by ascending paper chromatography. Development was accomplished using n-butanol acetic acid water (80 + 20 + 20, v/v).

5.3 Bivalve Reproduction

Samples of Mytilus edulis and Corbicula fluminea were preserved in Bouin's fixative after each collecting effort. Bivalves were opened to facilitate the entry of fixative into the mantle cavity. After three to five days of fixation, the bivalves were transferred to 70% isopropanol. Gonadal tissue was dissected from four specimens, from each station, for each effort. The dissected tissue was dehydrated and embedded in 62°C paraffin wax. Sections were cut at 10 microns and stained in Hematoxylin and Eosin. Slides were analyzed using a Leitz microscope, Xenon lamp and mechanical stage. Various stages of gonadal development were photographed using Kodak Tri X pan film (400 ASA) at either 1/60 or 1/125 second exposure. Because the study was of short duration, only animals from first and fourth efforts were analyzed.

6. SAMPLING FREQUENCY

Sampling was conducted a total of four times at each of the three sampling locations described in Section 4. The time intervals between the first and second, second and third, and third and fourth were 15, 15, and 30 days, respectively, depending on tidal cycles and weather conditions. The first sampling effort at each station included hourly sampling for 24 hours, and thereby encompassed a complete tidal cycle. The remaining samples were collected at slack tides following ebb tides. Table 6-1 summarizes the type and frequency of sample collection. Table 6-2 summarizes the different sampling dates for each of the three sampling sites.

Bivalve test organisms were placed in the field at Mare Island and Port Chicago approximately 30 days prior to the first sampling effort. This was done to allow the bivalves to acclimate to the environment into which they had been transplanted. The delays in establishing the Treasure Island station (see Section 3.3 and 5.1.10) prevented acclimating the test organisms for a length of time similar to that used at Mare Island and Port Chicago. At the Treasure Island site, the test organisms were placed in the field during the first sampling effort. In order to maintain four collections of test organisms at Treasure Island, an extra sampling trip was made to obtain the fourth group of test organisms 14 days after the final collection of water quality and sediment/substrate samples. During this final sampling effort, native *Mytilus edulis*, attached to pilings of the sampling site were also collected. These mussels were taken in addition to those required by the established sampling program. No concurrent water quality or sediment/substrate samples were obtained at this time.

In the pilot study, field samples were collected at "slack after ebb tide" as specified by the Corps in the Scope of Services. In this manner, the interval of sampling effort is standardized for all collection efforts. Secondly, it is implied that there is a difference between low tide and high tide levels of the parameter or constituent being measured (e.g., D.O., salinity, trace elements, PCBs). This pilot study was not designed to critically investigate the contaminant levels in the water column and suspended particulates between low and high tidal phases.

TABLE 6-1 . SAMPLING FREQUENCIES

SAMPLE \ ANALYSIS	Temperature	Turbidity	Suspended Solids	Settleable Solids	Salinity	Dissolved Oxygen	Nitrogen	Metals[1]	PCB	Color	Weight	Health	Species Identification	Other Observations[2]
Water	H[3]	H	H	H	H	H	H	D[4]	D					H
Suspended Particulate							D	D	D					D
Settled Particulate							D	D	D					D
Bottom							B[5]	B	B				B	B
Mytilus edulis								D	D	D	D	D	D	D
Corbicula fluminea								D	D	D	D	D	D	D
Artificial Substrate								S[6]	S	S	S	S	S	S

[1] As, Cd, Cu, Pb, Hg, Ni, Se, Ag, Zn, Cr.
[2] Weather, Wind, Wave, Water, Time, Tide.
[3] Once per sample day, plus hourly for one tidal cycle.
[4] Once per sample day.
[5] Beginning and end of test period.
[6] Two 30-day samples and one 60-day sample.

TABLE 6-2. SAMPLING DATES

Station Location	Sampling Effort	Date
Mare Island	Field placement of test organisms	2/12/79
	1 (included 24 hour sampling)	3/8-9/79
	2	3/23/79
	3	4/06/79
	4	5/07/79
Port Chicago	Field placement of test organisms	2/20/79
	1 (included 24 hour sampling)	3/13-14/79
	2	3/30/79
	3	4/13/79
	4	5/14/79
Treasure Island	1 (included 24 hour sampling and placement of test organisms)	4/10-11/79
	2	4/24/79
	3	5/09/79
	4	6/04/79
	†† Last collection of test organisms, see text.	6/18/79

7. DATA ANALYSIS

Results obtained from the field sampling program are tabulated in Appendix A. The data has been arranged either by sampling station or by the nature of laboratory analysis performed.

7.1 Explanation of Data Analysis

As explained in Section 1, the secondary objective of this pilot study is to provide an initial data set for the proposed long-term monitoring project.

The data have been presented largely in graphic and tabular summaries so that an overview of the results can be obtained quickly. These data can be used during future studies to more critically examine the problems encountered in this pilot study, and the resultant recommendations.

Aside from basic statistics (mean, variance, confidence intervals, etc.) calculated from the data, a series of Student's t tests were performed to detect changes in test organism tissue trace element burdens. Such information is helpful in examinations of organisms' rates of response to changes in ambient trace element levels.

7.2 Replication of Samples

Replication of samples was very limited in this pilot study because of the unavailability of sufficient funds. Field samples of the water column, artificial substrate, settled particulates and bottom sediment were replicated only during one sampling period. Replicates were made at the following stations and times: Water Column, March 8, 1979, Mare Island (Table 7-5); Water Column (trace elements), Treasure Island, May 9, 1979 (Table 7-1); Artificial Substrate (trace elements), Mare Island, April 6, 1979 (Table 7-2); Artificial Substrate, Treasure Island, June 4, 1979 (Table 7-4); Settled Particulates, Treasure Island, May 9, 1979 (Table 7-3); Bottom Sediment, Mare Island, March 8, 1979 (Table 7-6, 7-7); Suspended Particulates, Mare Island, March 8, 1979 (Table 7-8). Samples of bivalves consisted of five pooled individuals per field replicate (Tables 7-9 to 7-12).

7.3 Twenty-Four Hour Water Quality Sampling

A variety of water qualtiy determinations were made at hourly intervals for 24 hours at each of the three sampling sites. These measurements included salinity, dissolved oxygen (D.O.), settleable

TABLE 7-1. TREASURE ISLAND - EFFORT #3, May 9, 1979 - WATER COLUMN ($\mu g/L$)

Trace Element	Field Replicate 1	2	$\bar{X}$	S.D.	C.V.
Ag	2.3	2.4	2.35	0.07	3.01
As	11	11	11		
Cd	0.49	0.52	0.51	0.02	4.20
Cr	4.6	4.9	4.75	0.21	4.47
Cu	4.3	5.7	5.0	0.99	19.80
Hg	0.67	0.54	0.61	0.09	15.19
Ni	35	29	32.0	4.24	13.26
PbI	< 1	< 1	< 1		
PbII	< 1	< 1	< 1		
PbIII	18	6.20	12.10	8.34	68.96
Se	6.9	6.9	6.90		
Zn	39	31	35.00	5.66	16.16

$\bar{X}$ = Mean.
S.D. = Standard deviation.
C.V. = Coefficient of variation.

TABLE 7-2. MARE ISLAND - EFFORT #3, APRIL 6, 1979 - ARTIFICIAL SUBSTRATE (μg/tube)

Trace Element	Field Replicate 1	2	$\bar{X}$	S.D.	C.V.
Ag	6.1	12	9.05	4.17	46.10
As	< 1	< 1	< 1		
Cd	0.10	2.0	1.05	1.34	127.95
Cr	1.3	2.7	2.00	0.99	49.50
Cu	0.51	2.7	1.61	1.55	96.48
Hg	< 0.1	< 0.1	< 0.1		
Ni	1.5	0.5	1.00	0.71	70.71
Pb	< 1	< 1	< 1		
Se	< 1	< 1	< 1		
Zn	30	120	75.00	63.64	84.85

$\bar{X}$ = Mean.
S.D. = Standard deviation.
C.V. = Coefficient of variation.

TABLE 7-3. TREASURE ISLAND - EFFORT #3, MAY 9, 1979 - SETTLED PARTICULATES ($\mu g/g$)

Trace Element	Field Replicate 1	2	$\bar{X}$	S.D.	C.V.
Ag	3.2	1.0	2.10	1.56	74.08
As	14	6	10	5.66	56.57
Cd	2.4	2.0	2.20	0.28	12.86
Cr	140	100	120.00	28.28	23.57
Cu	210	170	190	28.28	14.89
Hg	0.79	0.43	0.61	0.25	41.73
Ni	87	93	90.00	4.24	4.71
Pb	23	17	20.00	4.24	21.21
Se	8	12	10.00	2.82	28.28
Zn	170	160	165.00	7.07	4.29

$\bar{X}$ = Mean.
S.D. = Standard deviation.
C.V. = Coefficient of variation.

TABLE 7-4. TREASURE ISLAND - EFFORT #4, JUNE 4, 1979 - ARTIFICIAL SUBSTRATE (μg/tube)

Parameter	Field Replicate 1	2	$\bar{X}$	S.D.	C.V.
Total Organic Carbon	190	419	304.50	161.93	53.18
Chlorophyll a	3.6	15	9.30	8.06	86.68
Volatile Solids	110	300	205	134.35	65.54

$\bar{X}$ = Mean.
S.D. = Standard deviation.
C.V. = Coefficient of variation.

TABLE 7-5. MARE ISLAND - EFFORT #1, MARCH 8, 1979 - WATER COLUMN

Parameter	Field Replicate 1	2	$\bar{X}$	S.D.	C.V.
Turbidity (NTU)	40	40	40		
NO_3 (mg/L)	0.64	0.66	0.65	0.14	2.18
NH_3 (mg/L)	0.28	0.28	0.28		
Settleable Solids (mL/L)	< 0.2	< 0.2	< 0.2		
Nonfilterable Residue (mg/L)	47	43	45.0	2.83	6.29

$\bar{X}$ = Mean.
S.D. = Standard deviation.
C.V. = Coefficient of variation.

TABLE 7-6. MARE ISLAND - EFFORT #1, MARCH 8, 1979 - BOTTOM SEDIMENT (ug/g)

Parameter	Field Replicate 1	2	$\bar{X}$	S.D.	C.V.
NH_3	860	850	855	7.07	0.83
NO_3	6.9	7.0	6.95	0.07	1.02

$\bar{X}$ = Mean.
S.D. = Standard deviation.
C.V. = Coefficient of variation.

TABLE 7-7. MARE ISLAND - EFFORT #1, MARCH 5, 1979 - SEDIMENT ($\mu g/g$)

Trace Element	Field Replicate 1	2	$\bar{X}$	S.D.	C.V.
Ag	2.6	2.8	2.7	0.141	5.24
As	20	28	24	5.66	23.57
Cd	1.6	1.8	1.7	0.141	8.32
Cr	120	160	140	28.28	20.20
Cu	97	96	96.5	0.71	0.73
Hg	0.67	0.53	0.60	0.10	16.50
Ni	66	63	64.50	2.12	3.29
Pb	87	74	80.50	9.19	11.42
Se	2.0	2.1	2.05	0.07	3.45
Zn	180	140	160	28.28	17.68

$\bar{X}$ = Mean.
S.D. = Standard deviation.
C.V. = Coefficient of variation.

TABLE 7-8. MARE ISLAND - EFFORT #1, MARCH 8, 1979 - SUSPENDED PARTICULATES (μg/g)

Particulate Size Range	Trace Element	Field Replicate 1	Field Replicate 2	$\bar{X}$	S.D.	C.V.
≥ 4 μ	Ag	0.93	1.0	0.97	0.05	5.13
	As	10	5.5	7.75	3.18	41.06
	Cd	6.0	6.0	6.0	0	0
	Cr	99	95	97.00	2.83	2.92
	Cu	110	110	110	0	0
	Hg	1.6	1.6	1.6	0	0
	Ni	180	100	140.00	56.57	40.41
	Pb	15	29	22.00	9.90	45.00
	Se	43	41	42.00	1.41	3.37
	Zn	200	180	190	14.14	7.44
1 - 4 μ	Ag	0.93	0.89	0.91	0.03	3.11
	As	8.7	8.5	8.60	0.14	1.64
	Cd	7.2	11.0	9.10	2.69	29.53
	Cr	110	79	94.50	21.92	23.20
	Cu	110	130	120.00	14.14	11.79
	Hg	1.6	1.8	1.70	0.14	8.32
	Ni	200	190	195.00	7.07	3.63
	Pb	120	60	90.00	42.43	47.14
	Se	82	81	81.50	0.71	0.87
	Zn	160	120	140.00	28.28	20.20
0.071 - 1.0 μ	Ag	1.5	1.3	1.40	0.14	10.10
	As	6.4	6.4	6.4	0	0
	Cd	13	10	11.50	2.12	18.45
	Cr	180	160	170.00	14.14	8.32
	Cu	150	110	130.00	28.28	21.76
	Hg	1.9	1.9	1.9	0	0
	Ni	340	280	310	42.43	13.69
	Pb	100	280	190.00	127.28	66.99
	Se	72	86	79.00	9.90	12.53
	Zn	150	180	165.00	21.21	12.86

$\bar{X}$ = Mean.
S.D. = Standard deviation.
C.V. = Coefficient of variation.

TABLE 7-9. TRACE ELEMENT ANALYSIS OF THE BIVALVE *Corbicula fluminea*[2] - "BACKGROUND" TISSUE DATA (μg/g dry weight tissue)

Trace Element	Field Replicate 1	2	$\overline{X}$	S.D.	C.V.
Ag	1.3	6.7	4.0	3.8	95.5
As	18	18	18.0	0	0
Cd	0.2	0.6	0.4	.3	70.7
Cr	4.4	4.8	4.6	.3	6.1
Cu	21	33	27.0	8.5	31.4
Hg	N.D.†	0.09	.045	.06	141.4
Ni	6.1	3.9	5.0	1.6	31.1
Pb	0.3	1.5	0.9	.8	94.8
Se	16	18	17	1.4	8.3
Zn	290	410	350	84.6	24.2

---

5 individuals / species pooled for each replicate ; all individuals from the same size class (20 to 40 mm).

$\overline{X}$ = mean

S.D. = standard deviation

C.V. = coefficient of variation

† = N.D. = none detectable for computations, assumed 0.0

[2] *Corbicula fluminea* obtained from commercial clammer in Antioch on February 12, 1979

TABLE 7-10. TRACE ELEMENT ANALYSIS OF THE BIVALVE *Mytilus edulis*[1] - "BACKGROUND" TISSUE DATA (μg/g dry weight tissue)

Trace Element	Field Replicate 1	2	$\overline{X}$	S.D.	C.V.
Ag	3.7	1.1	2.4	1.8	76.6
As	10	18	14	5.7	40.4
Cd	0.9	1.3	1.1	0.3	25.7
Cr	0.8	1.0	0.9	0.1	15.7
Cu	32	48	40	11.3	28.3
Hg	0.59	0.41	0.5	0.1	25.5
Ni	4.9	4.5	4.7	0.3	6.0
Pb	1.4	2.6	2.0	0.8	42.3
Se	10	18	14.0	5.6	40.4
Zn	290	310	300	14.1	4.7

---

5 individuals pooled for each replicate; all individuals from the same size class (45 to 59.9 mm).

$\overline{X}$ = mean

S.D. = standard deviation

C.V. = coefficient of variation

[1] *Mytilus edulis* collected from Pt. Richmond area on February 12, 1979

TABLE 7-11. TRACE ELEMENT ANALYSIS OF THE BIVALVE (NATIVE) Mytilus edulis COLLECTED ON JUNE 18, 1979 (μg/g dry weight tissue)

Trace Element	Field Replicate 1	2	$\bar{X}$	S.D.	C.V.
Ag	1.8	3.5	2.65	1.202	45.36
As	9.0	7.4	8.2	1.131	13.79
Cd	5.2	5.4	5.3	.141	2.66
Cr	5.0	4.3	4.65	.495	10.65
Cu	13	15	14	1.414	10.1
Hg	0.31	0.62	.465	.219	47.1
Ni	2.7	2.3	2.5	.283	11.32
Pb	4.1	2.2	3.15	1.34	4.25
Se	1.2	0.9	1.05	.212	20.19
Zn	190	220	205	21.213	10.35

M. edulis from pier used for sampling at Treasure Island.

5 individuals were pooled for each replicate; all individuals from the same size class (45 to 59.9 mm).

TABLE 7-12. TRACE ELEMENT ANALYSIS OF THE BIVALVE (TRANSPLANTED) *Mytilus edulis* COLLECTED JUNE 18, 1979 (μg/g dry weight tissue)

Trace Element	Field Replicate 1	2	$\overline{X}$	S.D.	C.V.
Ag	1.9	1.3	1.6	0.424	26.5
As	4.6	7.9	6.25	2.333	37.28
Cd	9.3	9.4	9.35	0.071	0.76
Cr	6.5	5.8	6.15	0.495	8.05
Cu	19	13	16.0	4.243	26.5
Hg	0.44	0.44	0.44	0	0
Ni	3.0	2.95	2.95	0.071	2.41
Pb	2.6	2.5	2.55	0.071	2.78
Se	1.9	1.7	1.8	0.141	7.83
Zn	280	270	275	7.071	2.57

M. edulis were transplanted from Point Richmond and used as the test organisms.

5 individuals per field replicate were pooled together and analyzed. All individuals were from the same size class (45 to 59.9 mm).

solids, nonfilterable residue (NFR), ammonia- and nitrate-nitrogen, turbidity and tidal height. The tidal height at each hour of collection was calculated using a computer program which uses the predictions of the annual Tide Tables. On the basis of a cosine function, this program applies correction factors to the predicted tidal time and height at the Golden Gate Bridge to predict the tidal height at a given time at a subordinate tidal station near each sampling site. The pairing of subordinate tidal stations and sampling sites was as follows: Mare Island - Selby; Port Chicago - Port Chicago; Treasure Island - Oakland Pier.

Examination of the data in Appendix A reveals that not all water quality parameters varied detectably over a tidal cycle at each sampling site. At Mare Island, settleable solids were consistently less than 0.2 mL/liter. Salinity was less than one part per thousand at Port Chicago, and settleable solids never exceeded 0.1 mL/liter. Nitrate decreased from 0.2 mg/L to 0.1 mg/L on only one occasion, and only three times did ammonia exceed 0.2 mg/L (0.5 mg/L during the first hour and 0.8 mg/L during the last two hours of sampling). The mean and 95% confidence limits were calculated for the remaining water quality parameters which were found to vary throughout the 24 hours of sampling (Table 7-13). Figures 7-1 through 7-10 illustrate the variation of selected parameters throughout the tidal cycle sampled.

San Francisco Bay system tides are not true tides, but are translated waves or "free tides" induced by oceanic lunar tidal waves. Each semidiurnal tidal cycle consists of four phases; high-high, low-high, high-low, and low-low. The average time between phases is approximately 6.2 hours; the average time required for the completion of one tidal cycle is approximately 24.8 hours. The tidal extremes were 5.8 feet at Mare Island, 4.6 feet at Port Chicago, and 4.6 feet at Treasure Island.

The salinity regimes at the three sampling stations clearly reflect the different environs where sampling occurred. At Treasure Island, the central San Francisco Bay location, salinity was relatively constant with a value of 26.6 ppt; 95% confidence interval from 26.1 to 27.1. Salinities observed at Mare Island in Carquinez Strait reflect the mixing of marine and fresh delta water. In this area, mean salinity was 8.3 ppt., ranging from 3.5 to 13.0 ppt. At the Suisun Bay station, Port Chicago, salinity was very low (less than one part per thousand).

7.4 Trace Elements

The mean, standard deviation, coefficient of variation and 95 percent confidence intervals for the levels of trace elements obtained at each sampling station for all four collection efforts, are presented in Figures 7-11 through 7-16 with the tabulated data summarized in Appendix A.

TABLE 7-13.

SUMMARY OF WATER QUALITY

Parameters Sampled Hourly
For 24 Hours at Each Sampling Site

STATION	DATE	PARAMETER	$\overline{X}$	LCI	UCI	n
Mare Island	3/8-9/79	Salinity	8.275	7.261	9.289	24
		D.O.	8.833	8.668	8.999	24
		Nonfilterable Residue	90.25	28.71	151.790	24
		Ammonia	0.346	0.284	0.409	24
		Nitrate	0.636	0.586	0.686	24
		Turbidity	27.667	21.086	34.247	24
Port Chicago	3/13-14/79	D.O.	9.525	9.445	9.605	24
		Nonfilterable Residue	69.083	57.437	80.589	24
		Ammonia	0.328	0.291	0.364	24
		Nitrate	0.758	0.728	0.788	24
		Turbidity	48.042	43.973	52.111	24
Treasure Island	4/10-11/79	Salinity	26.575	26.085	27.065	24
		D.O.	7.804	7.541	8.067	24
		Ammonia	0.200	0.114	0.286	24
		Turbidity	21.292	18.762	23.821	24
		Settleable NFR	40.958	35.609	46.308	24

$\overline{X}$ = Mean

LCI = Lower 95% confidence interval

UCI = Upper 95% confidence interval

FIGURE 7-1

TIDAL CURVE
MARE ISLAND
MARCH 8-9, 1979

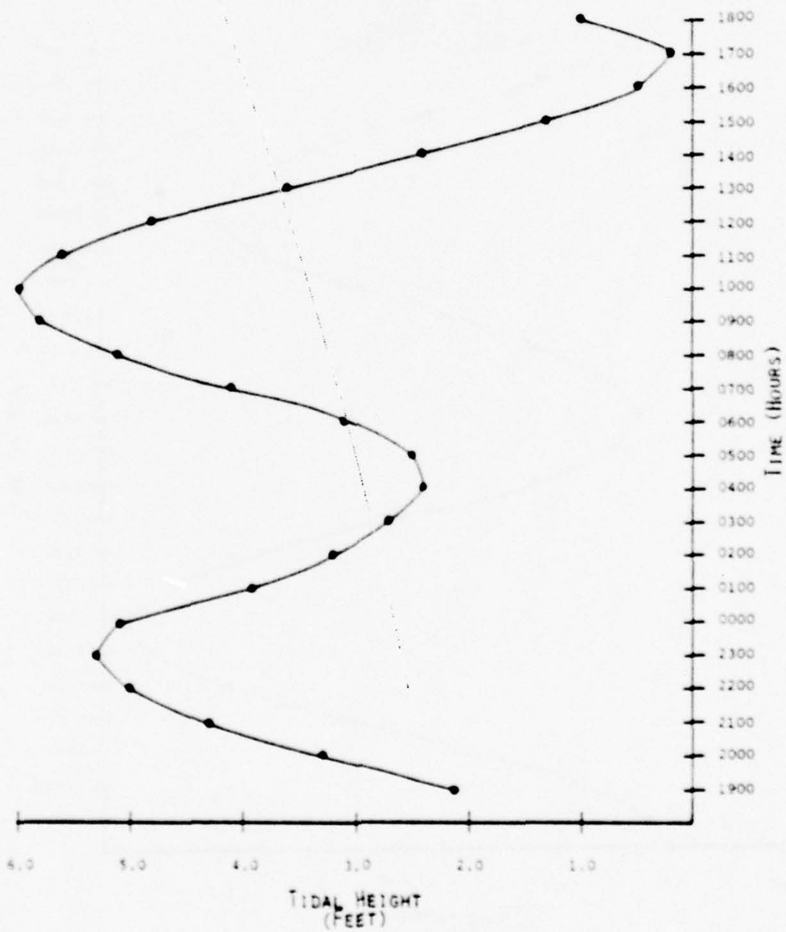


FIGURE 7-2

Tidal Curve
Port Chicago
March 13-14, 1979

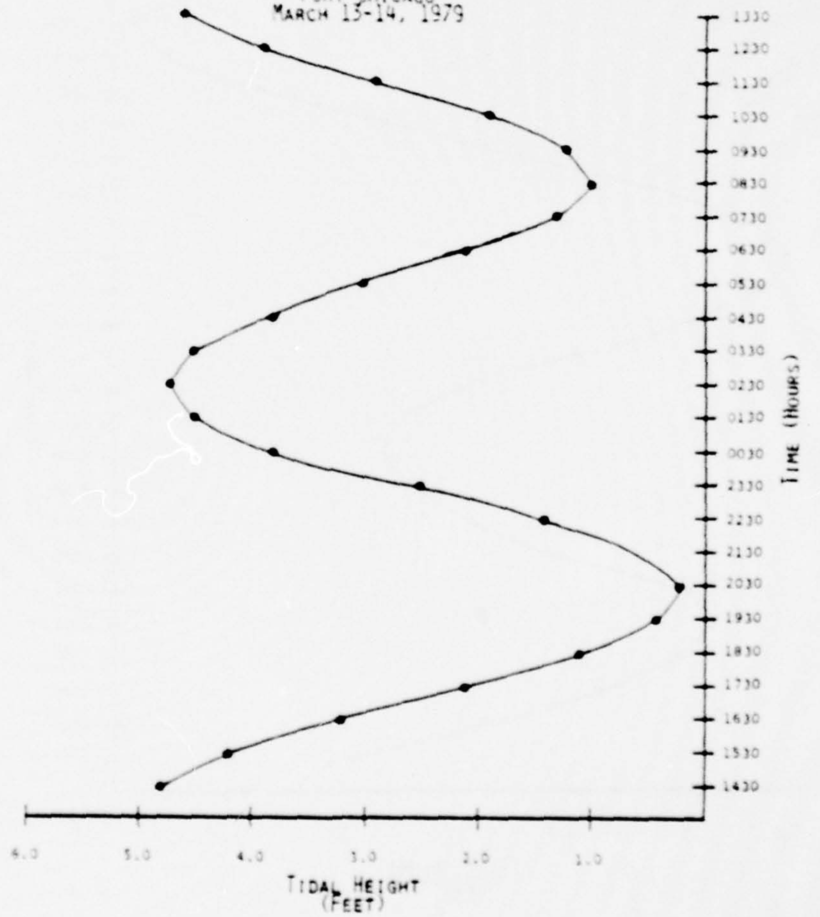


FIGURE 7-3

Tidal Curve
Treasure Island
April 10-11, 1979

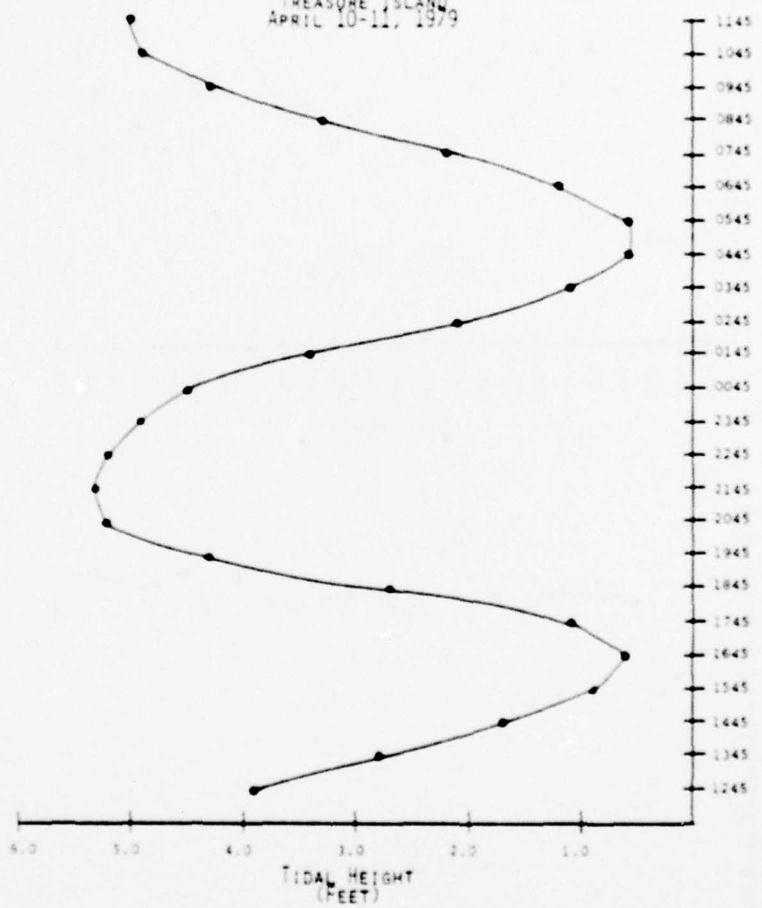
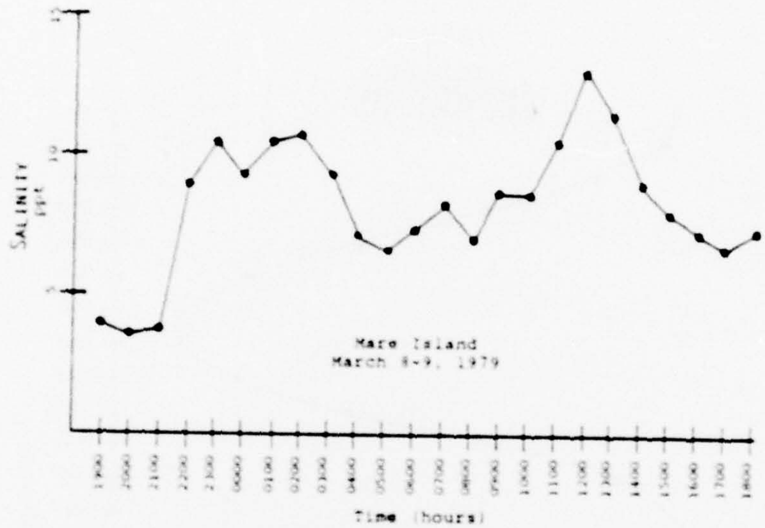


FIGURE 7-4

SALINITY REGIMES



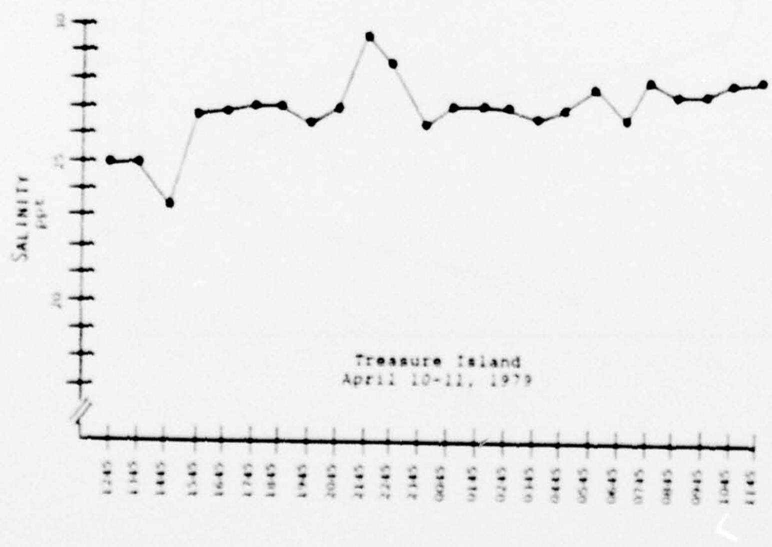
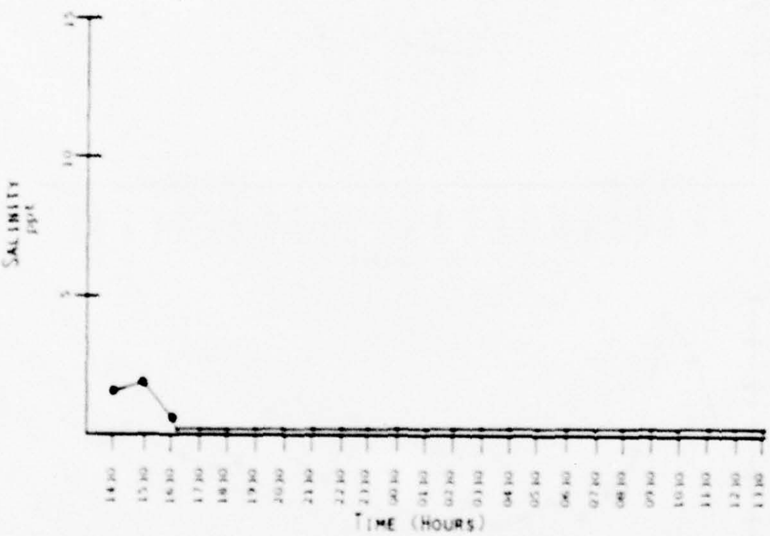


FIGURE 7-5

PORT CHICAGO
SALINITY REGIME
MARCH 13-14, 1979



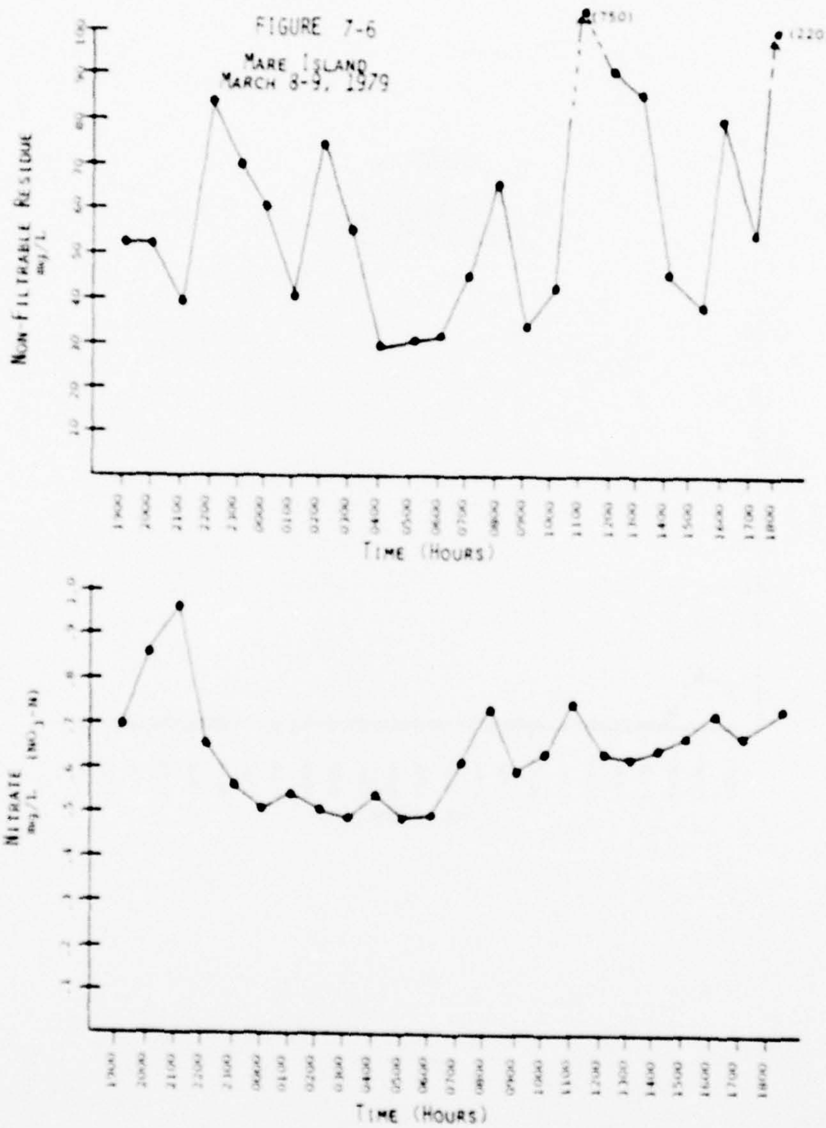


FIGURE 7-6
MARE ISLAND
MARCH 8-9, 1979
NON-FILTRABLE RESIDUE mg/l
(750)
(220)
TIME (HOURS)
NITRATE mg/l (NO3-N)
TIME (HOURS)

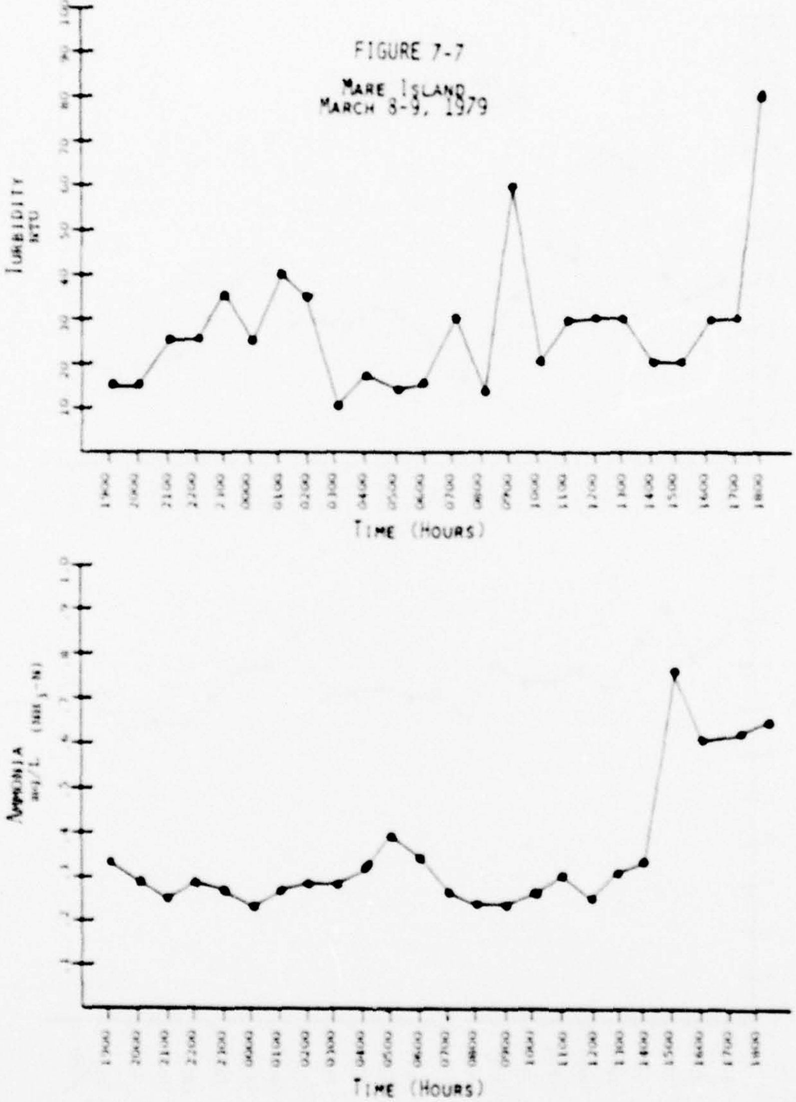


FIGURE 7-7

Mare Island
March 8-9, 1979

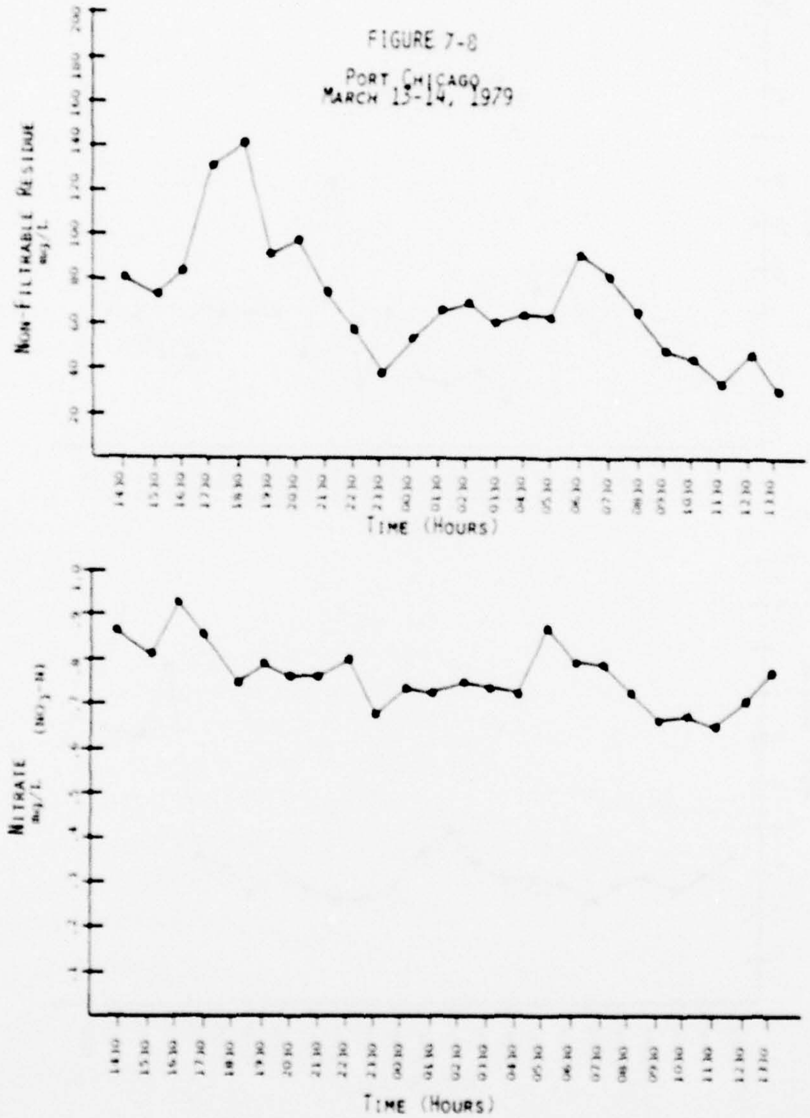


FIGURE 7-8
PORT CHICAGO
MARCH 13-14, 1979
NON-FILTRABLE RESIDUE mg/L
TIME (HOURS)
NITRATE mg/L (NO3-N)
TIME (HOURS)

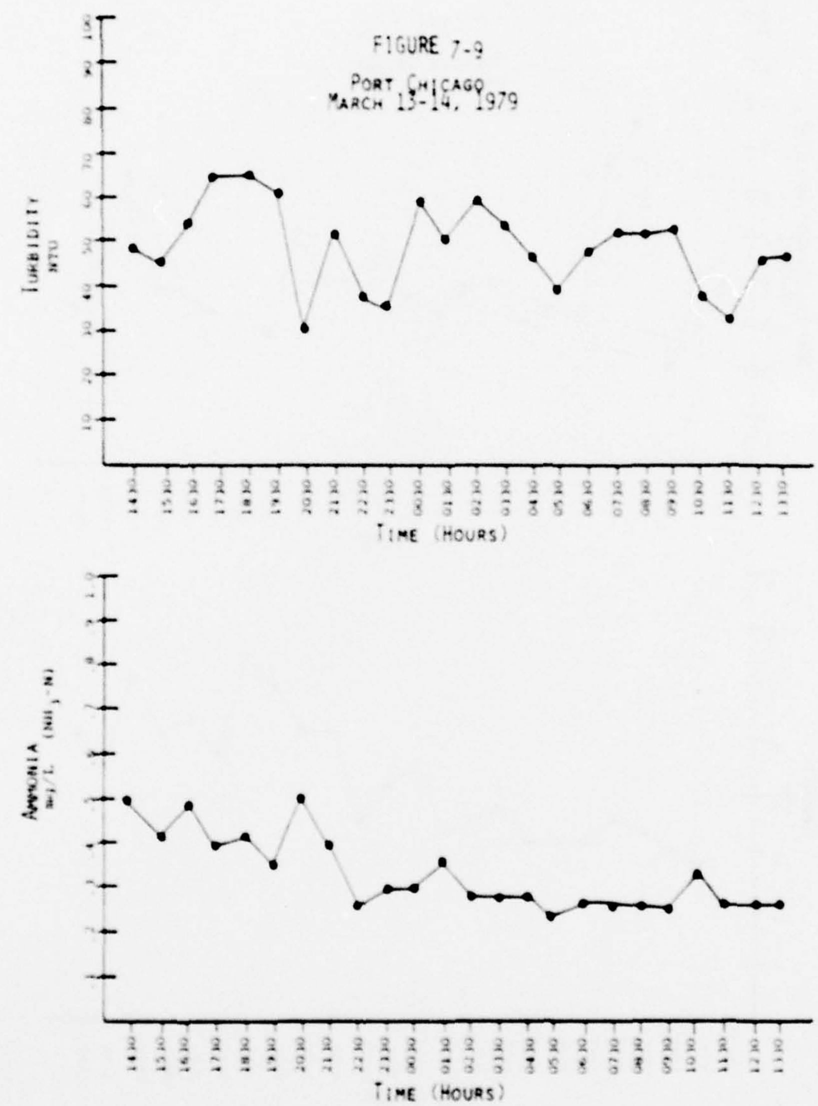


FIGURE 7-9
PORT CHICAGO
MARCH 13-14, 1979
TURBIDITY
NTU
TIME (HOURS)
AMMONIA
mg/L (NH3-N)
TIME (HOURS)

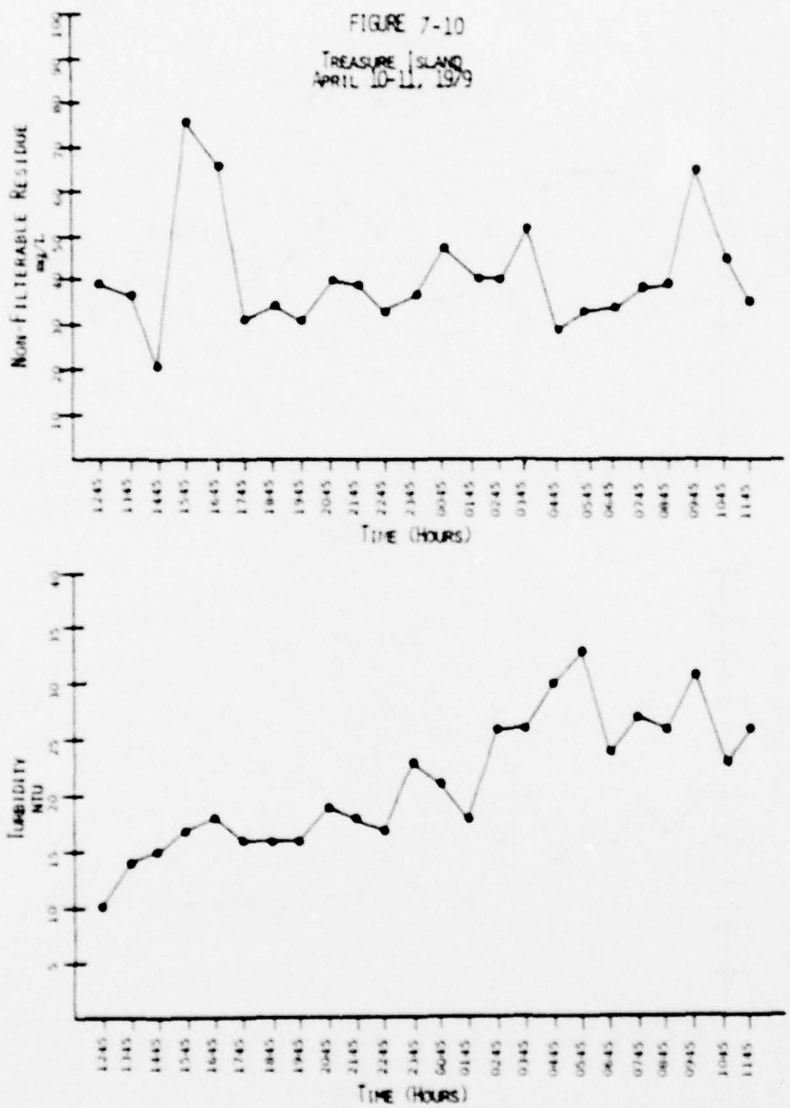
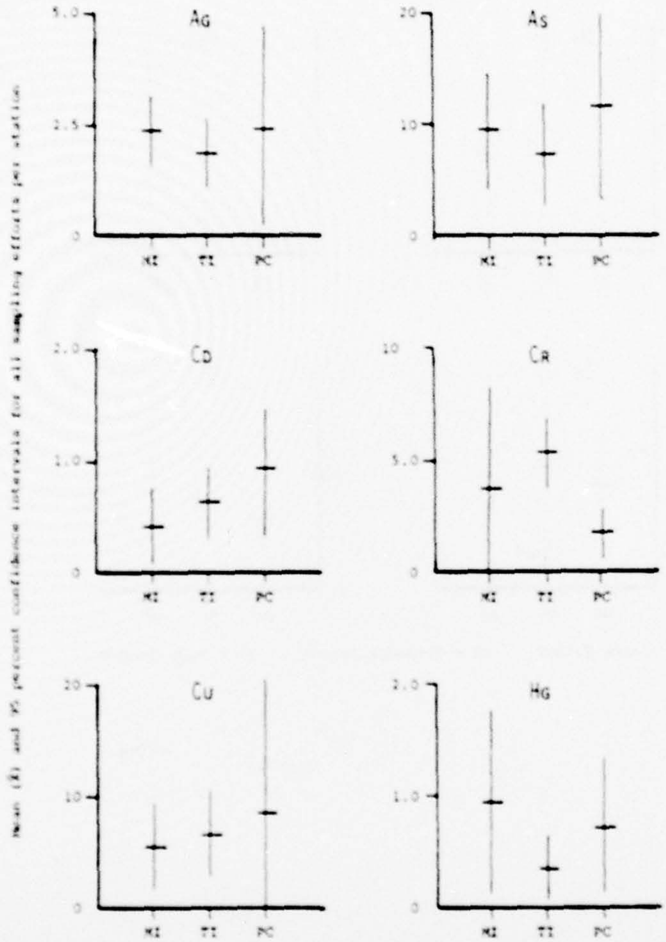


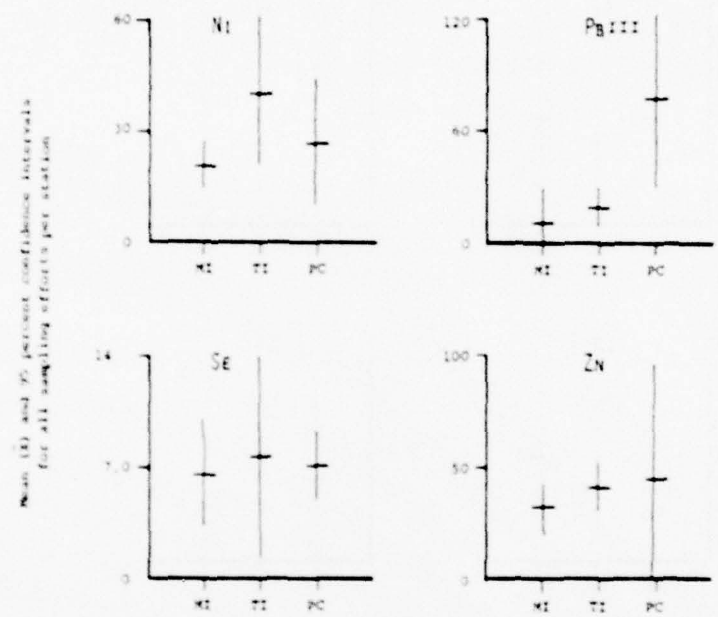
FIGURE 7-10
TREASURE ISLAND
APRIL 10-11, 1979
NON-FILTERABLE RESIDUE
mg/l
TIME (HOURS)
TURBIDITY
NTU
TIME (HOURS)

FIGURE 7-11.
WATER COLUMN (µg/L)



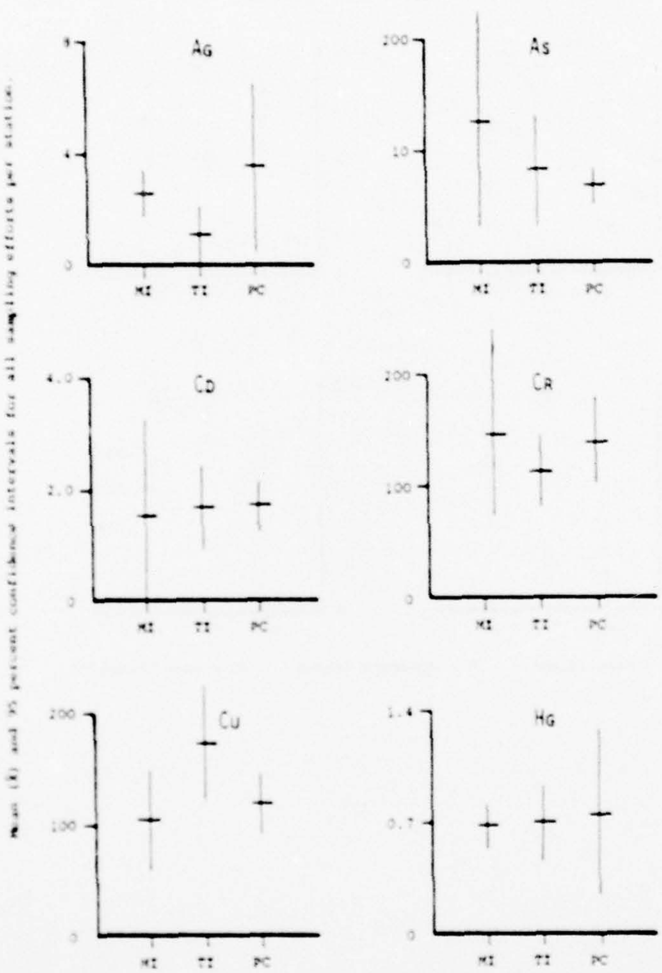
MI = Mare Island TI = Treasure Island PC = Port Chicago

Figure 7-11 (cont.)
WATER COLUMN, cont. (µg/L)



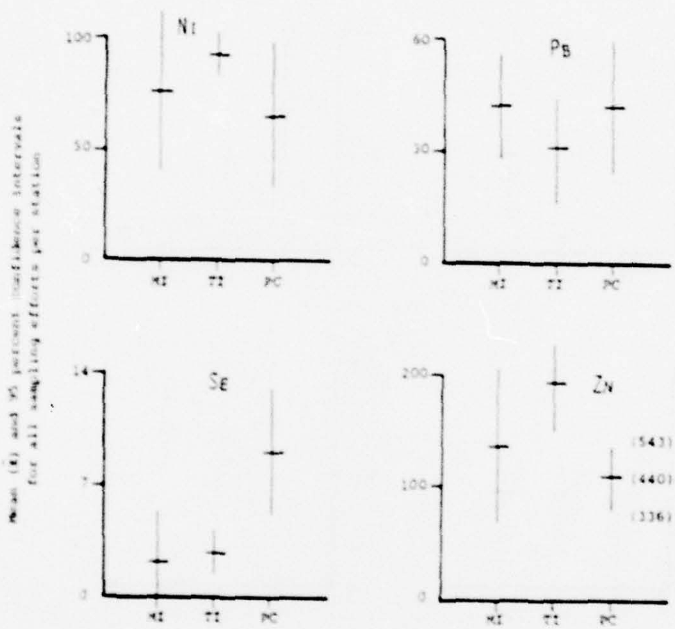
MI = Mare Island TI = Treasure Island PC = Port Chicago

FIGURE 7-12.
SETTLED PARTICULATES (µg/mg)



MI = Mare Island   TI = Treasure Island   PC = Port Chicago

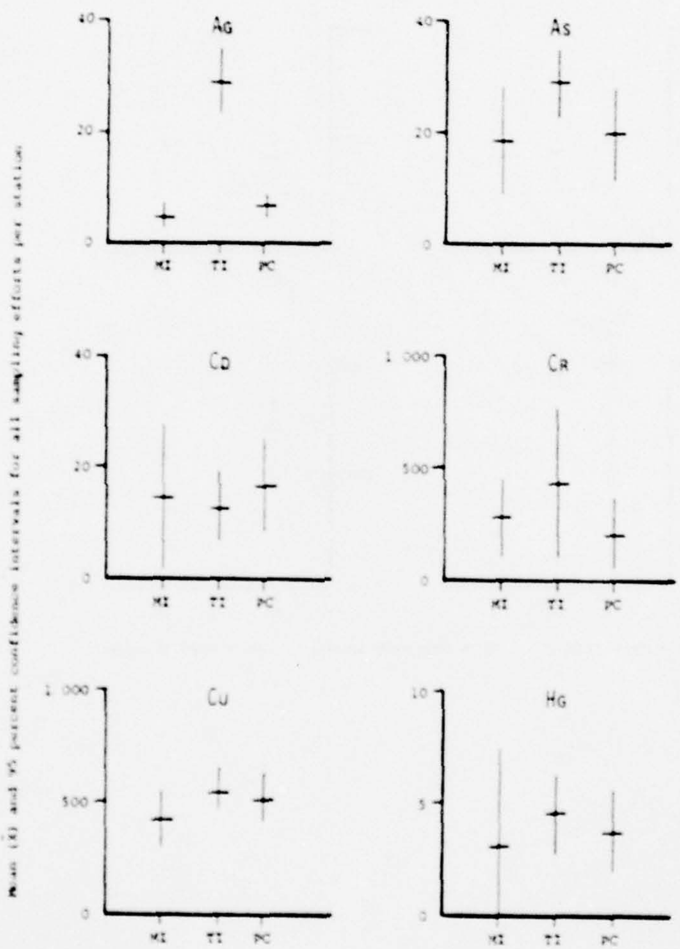
Figure 7-12 (cont.)
SETTLED PARTICULATES, cont. (ug/mg)



MI = Mare Island TI = Treasure Island PC = Port Chicago

FIGURE 7-13.

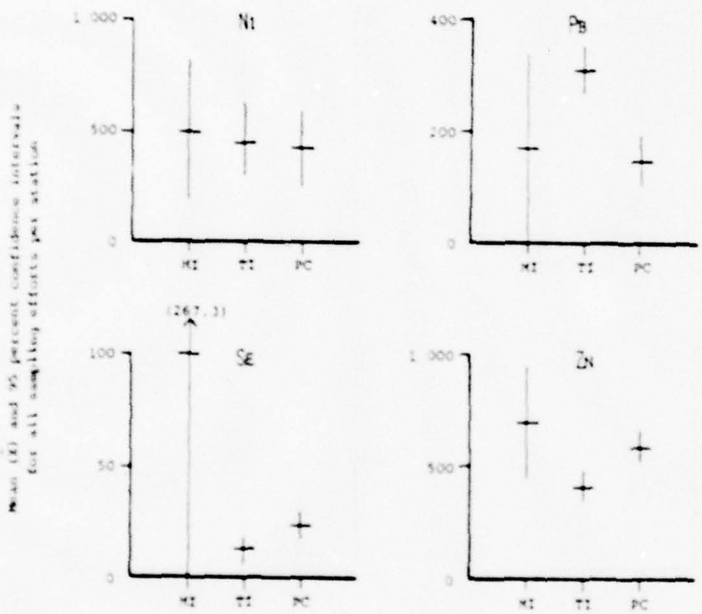
TOTAL SUSPENDED PARTICULATES (µg/mg)



MI = Mare Island   TI = Treasure Island   PC = Port Chicago

Figure 7-13. (cont.)

TOTAL SUSPENDED PARTICULATES, cont. (ug/mg)



MI = Mare Island TI = Treasure Island PC = Port Chicago

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PILOT WATER QUALITY MONITORING STUDY, SAN FRANCISCO BAY AND DEL--ETC(U)
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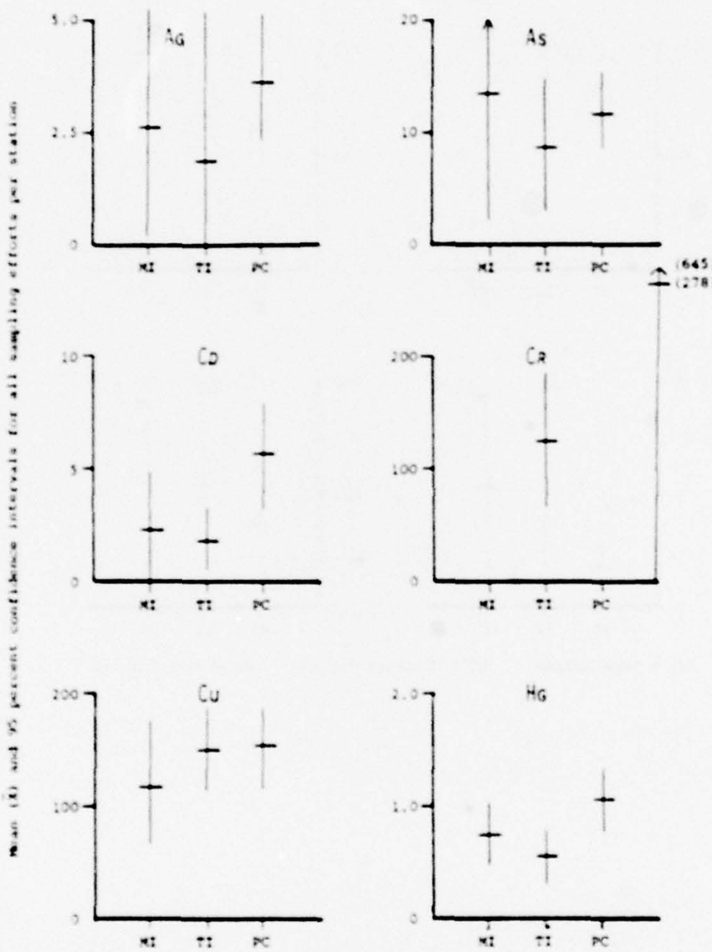
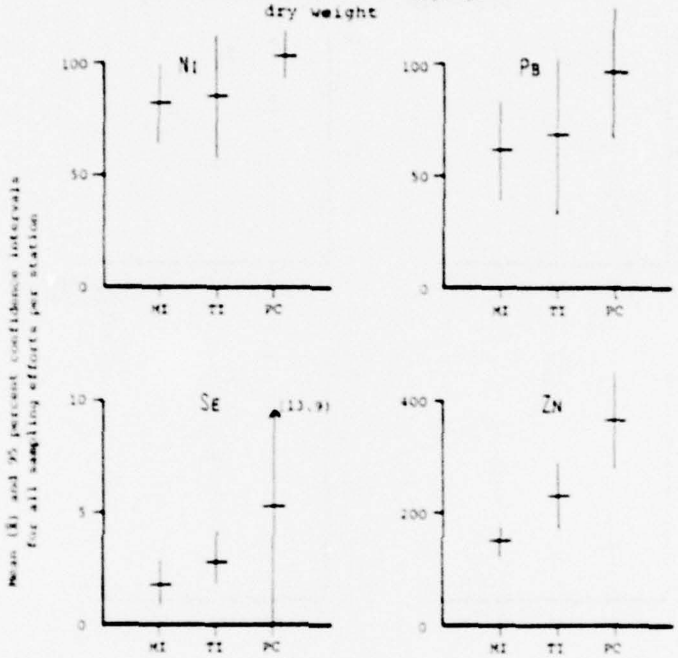
FIGURE 7-14.
BOTTOM SEDIMENT (µg/mg)
dry weight



MI = Mare Island TI = Treasure Island PC = Port Chicago

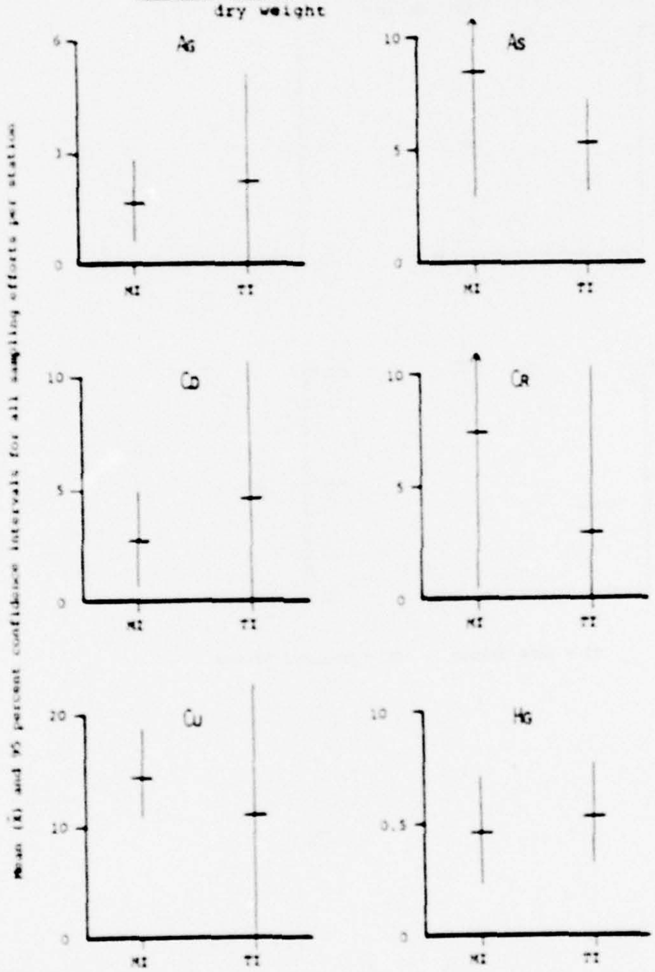
Figure 7-14 (cont.)
BOTTOM SEDIMENT, cont. (μg/mg)
dry weight



MI = Mare Island   TI = Treasure Island   PC = Port Chicago

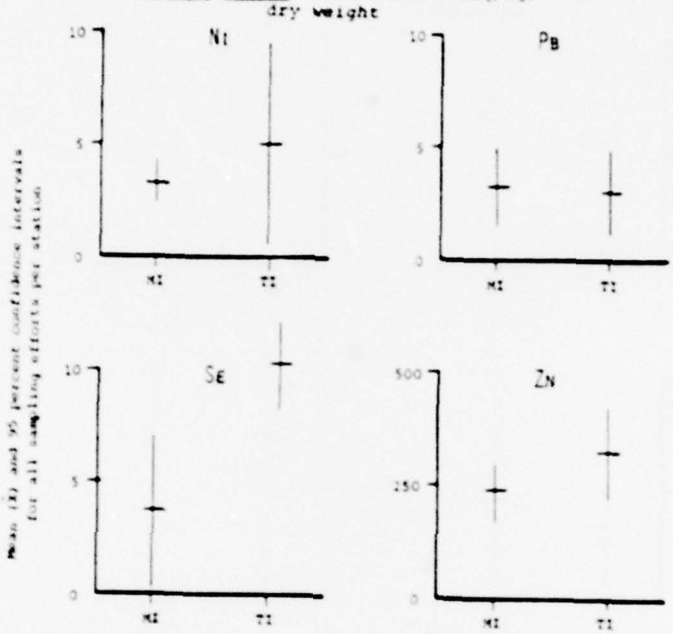
FIGURE 7-15.

<u>Mytilus</u> <u>edulis</u> TISSUE (μg/mg) dry weight



MI = Mare Island   TI = Treasure Island

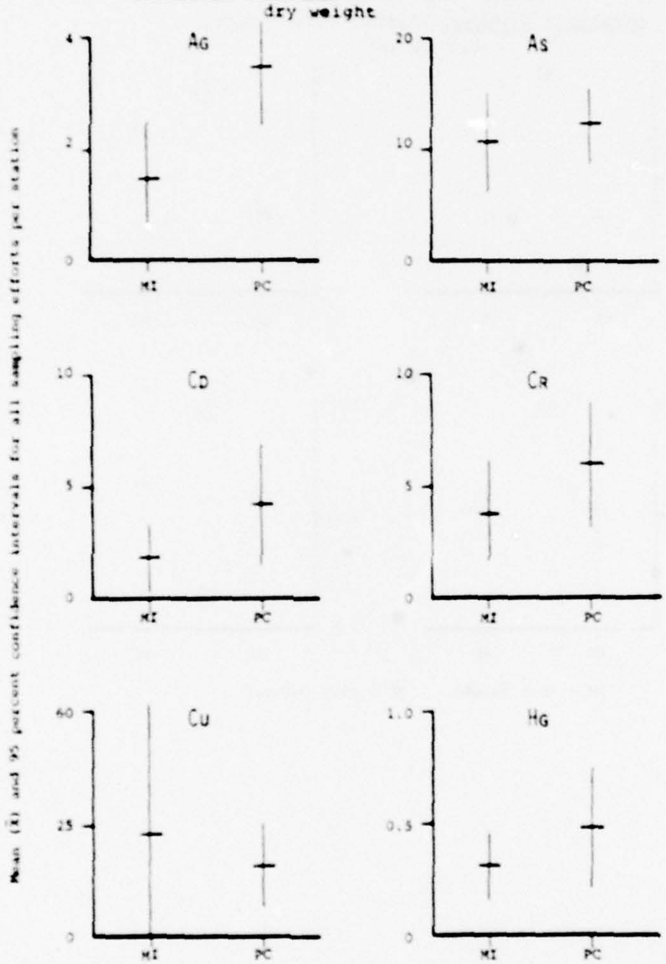
Figure 7-15. (cont.)
Mytilus edulis TISSUE, cont. (μg/mg) dry weight



MI = Mare Island   TI = Treasure Island

TABLE 7-16.

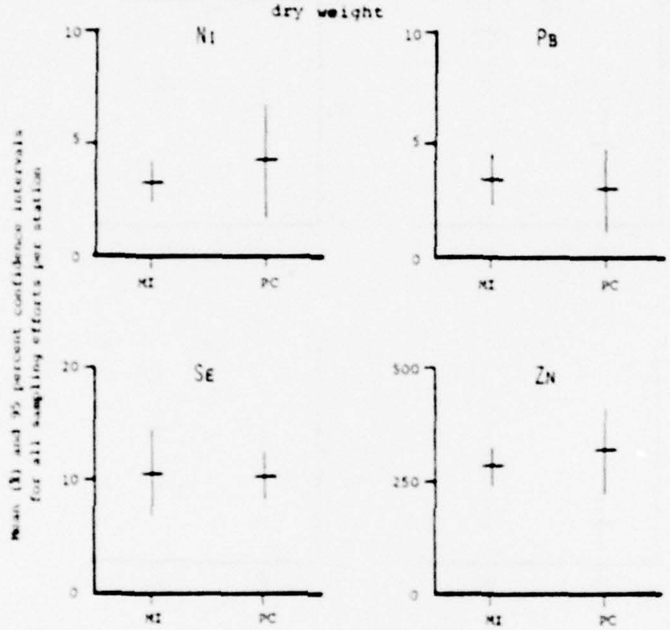
<u>Corbicula</u> <u>fluminea</u> TISSUE (μg/mg) dry weight



MI = Mare Island PC = Port Chicago

Table 7-16. (cont.)

Corbicula fluminea TISSUE, cont. (μg/mg)
dry weight



MI = Mare Island PC = Port Chicago

Apparent from these graphs is that very few recurrent trends in levels of trace elements between stations throughout the various types of samples exist. Mean levels of trace elements in bottom sediment were routinely highest at Port Chicago with the exception of arsenic, which was highest at Mare Island. Water column and settling particulate mean levels were typically highest at either Port Chicago or Treasure Island and mean levels of trace elements of total suspended particulates were typically highest at either Mare Island or Treasure Island. No reoccurring trends in the relative difference among mean levels of trace elements between stations per type of sample (as figured) were observed.

7.4.1 Suspended Particulates

The percent of total trace element amounts per size class of suspended particulate is presented in Tables 7-14 through 7-16. It is evident from these tables that, percentage-wise, substantial amounts of suspended particulates were present in all these size classes assayed. In general, the largest particle size collected is regulated by the intake velocity of the collection tube. The higher the intake velocity, the larger the particle size class collected. It is therefore essential that the intake velocity of the collection tube be carefully regulated and controlled. In this manner, the range of particle size of suspended particulates collected is maintained and direct comparison of this data is facilitated. In general, the percent of total trace elements was higher in the smaller particle sizes.

7.4.2 Bivalve Tissues

Individuals from five size classes of *M. edulis* and two size classes of *C. fluminea* were suspended as test organisms (Section 5.1.10). Of these organisms, only representatives of the 45 to 59.9 mm class of *M. edulis* and 20 to 40 mm class of *C. fluminea* were analyzed for contaminant levels. Individuals of the remaining size classes were preserved for possible future analyses.

Differences in tissue levels of trace elements throughout the study period has been statistically examined by using a Student's t test. Data available for this examination are the "background" tissue data (mean and variance from two replicated field samples) for *Corbicula* and *Mytilus*, as presented in Tables 7-9 and 7-10, respectively; and the single determination made for each trace element from each sampling effort for both *Corbicula* and *Mytilus*, as presented in Appendix A, pages A-17 through A-28. The appropriate t test is the comparison of a single observation with the mean of a sample (Sokal and Rohlf, 1968).

TABLE 7-14. MARE ISLAND - CONTRIBUTION OF TRACE ELEMENTS PER SIZE CLASS OF SUSPENDED PARTICULATES (%)

Sampling Effort	Particle Size (μ)	Ag	As	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn
1	≥ 4	30.21	35.29	22.30	26.72	30.56	30.77	21.88	6.67	20.90	38.78
	1 - 4	27.49	39.37	34.20	26.45	33.33	32.69	26.69	30.00	39.80	28.57
	0.07 - 1	42.30	28.96	43.49	46.83	36.11	36.54	48.44	63.33	39.30	32.65
2	≥ 4	33.33	43.54	45.38	33.67	26.95	36.00	27.97	14.12	27.07	30.43
	1 - 4	27.45	28.56	46.92	29.29	29.92	24.00	21.33	21.76	27.62	27.54
	0.07 - 1	39.22	27.89	7.69	37.04	43.13	40.00	50.70	64.12	45.30	42.03
3	≥ 4	35.85	40.32	19.33	25.60	24.53	24.00	34.55	27.53	69.31	22.09
	1 - 4	18.87	40.32	31.09	32.74	35.85	31.25	25.45	32.02	9.90	47.67
	0.07 - 1	45.28	19.35	49.58	41.67	39.62	43.75	40.00	40.45	20.79	30.23
4	≥ 4	15.52	29.84	24.69	11.20	22.54	4.00	40.91	21.74	16.33	30.26
	1 - 4	15.52	35.86	37.04	16.80	28.17	32.00	18.18	21.74	42.86	27.63
	0.07 - 1	68.97	24.30	38.27	72.00	49.30	64.00	40.91	56.52	40.82	42.11

TABLE 7-15. PORT CHICAGO - CONTRIBUTION OF TRACE ELEMENTS PER SIZE CLASS OF SUSPENDED PARTICULATES (%)

Sampling Effort	Particle Size (μ)	Ag	As	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn
1	≥ 4	26.74	37.10	20.93	26.96	16.98	16.67	28.57	24.24	25.17	28.57
	1 - 4	25.58	32.80	33.49	24.35	20.75	33.33	33.93	31.52	29.37	35.71
	0.07 - 1	47.67	30.11	45.58	48.70	62.26	50.00	37.50	38.18	45.45	35.71
2	≥ 4	57.97	34.15	18.81	20.93	21.05	13.04	21.79	19.27	17.55	32.79
	1 - 4	17.39	34.15	15.84	37.21	36.84	34.78	39.11	24.77	37.55	36.07
	0.07 - 1	24.64	31.71	65.35	41.86	42.11	52.17	39.11	55.96	44.90	31.15
3	≥ 4	36.36	44.52	21.89	25.30	32.56	19.57	27.03	47.06	26.91	21.88
	1 - 4	34.55	49.68	53.25	27.27	44.19	36.96	37.84	39.22	36.77	32.81
	0.07 - 1	29.05	5.81	24.85	47.43	46.51	43.48	35.14	13.33	36.32	45.31
4	≥ 4	37.70	18.52	13.09	9.68	20.37	18.18	24.39	25.00	16.92	27.59
	1 - 4	14.75	25.93	34.55	29.03	35.19	24.24	39.02	31.25	35.90	27.59
	0.07 - 1	47.54	55.56	52.36	61.29	44.44	57.58	36.59	43.75	47.18	44.83

TABLE 7-16. TREASURE ISLAND - CONTRIBUTION OF TRACE ELEMENTS PER SIZE CLASS OF SUSPENDED PARTICULATES (%)

Sampling Effort	Particle Size (μ)	Ag	As	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn
1	≥ 4	14.81	33.61	14.04	26.76	29.17	21.05	26.67	18.75	36.84	27.91
	1 - 4	33.33	31.93	42.11	33.80	31.25	28.07	31.11	37.50	33.33	32.56
	0.07 - 1	51.85	34.45	43.86	39.44	39.58	50.88	42.22	43.75	29.82	39.53
2	≥ 4	7.12	30.90	25.81	19.42	22.41	18.92	30.51	16.67	20.79	26.67
	1 - 4	30.96	27.43	34.41	37.19	36.21	32.43	28.81	20.00	39.60	37.78
	0.07 - 1	61.92	41.67	39.78	43.39	41.38	48.65	40.68	63.33	29.60	35.56
3	≥ 4	10.27	39.22	27.78	25.00	29.09	20.37	21.95	20.59	11.95	30.56
	1 - 4	17.49	31.37	16.67	32.14	29.09	35.19	46.34	32.35	25.16	25.00
	0.07 - 1	72.24	29.41	55.56	42.86	41.82	44.44	31.71	47.06	62.89	44.44
4	≥ 4	17.96	18.18	7.52	22.22	19.67	25.00	20.00	15.11	11.56	25.58
	1 - 4	16.17	36.36	17.29	14.81	31.15	22.22	34.29	23.74	27.21	18.60
	0.07 - 1	65.87	45.45	75.19	62.95	49.18	52.78	45.71	61.15	61.22	55.81

TABLE 7-17.

SUMMARY OF HEAVY METALS IN BIVALVE TISSUES AS
COMPARED TO THE MEAN BACKGROUND LEVELS
VIA 2 TAIL STUDENT'S T TEST; df = 1

Species/Location	Sampling Effort	Trace Elements Ag	As	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn
Mytilus edulis	1	-	-	-	•	-	-	-	-	-	-
Mare Island	2	-	-	-	•	-	-	-	-	-	-
	3	-	-	-	•	-	-	-	-	-	-
	4	-	-	-	•	-	-	-	-	-	-
Mytilus edulis	†	-	-	-	-	-	-	-	-	-	-
Treasure Island	2	-	-	•	-	-	-	-	-	-	-
	3	-	-	-	L.A.	-	-	-	-	-	-
	4	-	-	-	-	-	-	-	-	-	-
	††	-	-	•	•	-	-	-	-	-	-
Corbicula fluminea	1	-	x	-	-	-	-	-	-	-	-
Mare Island	2	-	x	-	-	-	-	-	-	-	-
	3	-	x	-	-	-	-	-	-	-	-
	4	-	x	-	-	-	-	-	-	-	-
Corbicula fluminea	1	-	x	-	-	-	-	-	-	-	-
Port Chicago	2	-	x	-	-	-	-	-	-	-	-
	3	-	x	•	-	-	-	-	-	-	-
	4	-	x	-	-	-	-	-	-	-	-

- = indicates no significant difference between sample & "background" mean.

• = indicates difference at 95% level ($P < 0.05$).

x = C. fluminea background variance for As - 0.0; therefore, t_s value cannot be calculated.

† = M. edulis obtained from Point Richmond area. These bivalves are considered as second out of background trace metal tissue data.

†† = M. edulis obtained from suspended racks at Treasure Island. Concurrent water quality samples not taken.

L.A. = Laboratory accident.

In this case, the single observation refers to the level of trace element in *Corbicula* and *Mytilus* tissues (the single determination presented in Appendix A); the mean of a sample corresponds to the "background" tissue data in Tables 7-9 and 7-10. This mean was derived from two (n=2) field replicate tissue samples. Therefore, the degrees of freedom equals 1. This is clearly a two-tailed test because the alternative hypothesis is that the mean of the transplanted population from which the single determination was made could be greater or less than the background population. The transplanted population were those individuals suspended at the three sampling sites. The background population were the indivdiuals of *Mytilus* collected at Point Richmond, and *Corbicula* obtained from Bales Bait Shop.

These results are summarized in Table 7-17, with the calculated t values presented in Table A-1, Appendix A. For *M. edulis*, significant changes in the levels of cadmium and chromium were detected. For *C. fluminea*, only one element, cadmium, is significantly different from background tissue levels.

Statistically speaking, this t test has been appropriately applied to the available data. It is recognized that the overall sensitivity of this test, or the ability to significantly detect more subtle differences, would be increased by using more data points. The most direct method to increase the sensitivity would be to increase the number of field replicates used to compute the "background" mean and variance. Such increased replication has been previously discussed in Section 2.

On June 18, 1979, the final set of suspended *Mytilus edulis* test organisms were collected from Treasure Island. At this same time, *M. edulis* inhabiting the pier from which the routine sampling occurred were also collected. Enough individuals from the test organisms (transplanted *M. edulis*) and individuals from the pier (native *M. edulis*) were available so that two replicates of five pooled individuals could be analyzed for the trace elements. This data is presented in Tables 7-11 and 7-12. The mean levels of trace elements in the tissues of transplanted and native *M. edulis* were compared by a Student's t test of two-sample means.. In this case, the hypothesis is $H_o: \bar{X}_1 \neq \bar{X}_2$, or a two-tail test of significance. Significant differences between sample means were found for the following trace elements: chromium and cadmium ($P < 0.01$), and nickel and zinc ($P < 0.05$). The remaining elements (silver, arsenic, copper, mercury, lead and selenium) showed no significant difference between transplanted and native *M. edulis*. The t values are presented in Appendix A, page A-42.

By comparing the levels of trace elements in "background" *M. edulis* collected from Point Richmond to the "native" *M. edulis* at Treasure Island, it was found that substantial differences occurred in three elements. Mean "background" levels of chromium and cadmium were 0.9 and 1.1 μg/mg, respectively. The native population had mean levels of these same elements of 4.65 and 5.3 μg/mg. There was also a substantial difference between mean levels of copper, being 40 μg/mg in "background" *M. edulis* and 14 μg/mg in the native population.

7.5 PCB Analysis

Observation of water column PCB data revealed that throughout the study time interval, PCB levels at the Mare Island station were substantially higher than those found at the other two stations. Also, no relatively large changes in PCB levels were observed to occur within the same station location.

Settling particulate samples and Aufwuchs settling tubes contained less than detectable traces of PCBs. Bivalve tissue also contained less than detectable traces at all stations. Sediment from the Treasure Island sampling site showed a considerably higher PCB burden than that from other sites. The facility engineer, a Mr. McCool, stated that several years earlier a large electrical transformer had fallen through the pier from which the samples were taken; thus there is a possibility that significant PCB contamination of sediments emanated from this transformer.

7.6 Artificial Substrate

The artificial substrate rack design (Figure 5-6) follows that developed by Alexander Horne for the collection of estuarine Aufwuch communities. Horne has used the collectors to detect changes of growth and metabolic rates of algae as in situ responses to point source discharges. Most of his work has been conducted in freshwater streams and lakes, and in the upper Sacramento River Delta. However, he has not analyzed the attached communities for trace element or PCB burdens.

Aufwuch collectors were placed in the field at each of the three stations during the first sampling effort conducted at those stations. During both sampling efforts 3 and 4, one acrylic rack (with collectors to be analyzed for trace elements) and one stainless steel rack (with collectors to be analyzed for PCB levels) were removed from each station.

Colonization of roughened glass collecting tubes was grossly nonuniform, both within and among stations; even growth on tubes within a given rack was extremely variable (see Table 7-18 and Figure 7-17).

Total organic carbon may be used as an indicator of net accumulation of organic matter on settling tubes, and chlorophyll a as an index of the amount of attached plant material. Volatile solids determinations may also be used as indices of total organic matter present on settling tubes. Attached algae, as is apparent from examination of chlorophyll a data, increased over time at each station; the greatest increase was observed at Port Chicago. Volatile solids and total organic carbon increased at all stations over time.

TABLE 7-18. BIOMASS ESTIMATES

Area	Sampling Effort	TOC μg/tube	Chlorophyll a mg/tube	Volatile Solids μg/tube
Mare Island	3	33	< 0.1	70
	4	79	27	90
Port Chicago	3	19	< 0.1	110
	4	56	40	90
Treasure Island	3	240	4.0	100
	4	300	9.0	194

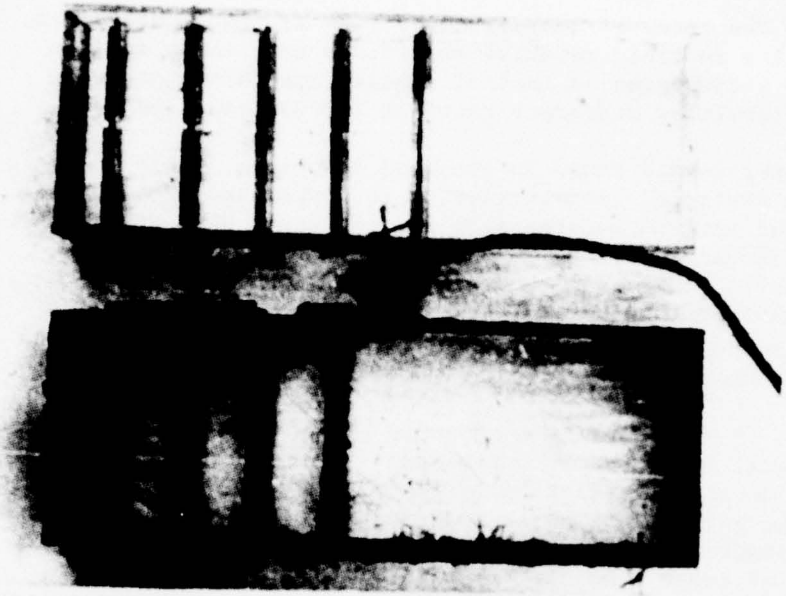


Fig. 7-17. Artificial substrate racks showing differences in growth on plastic racks.

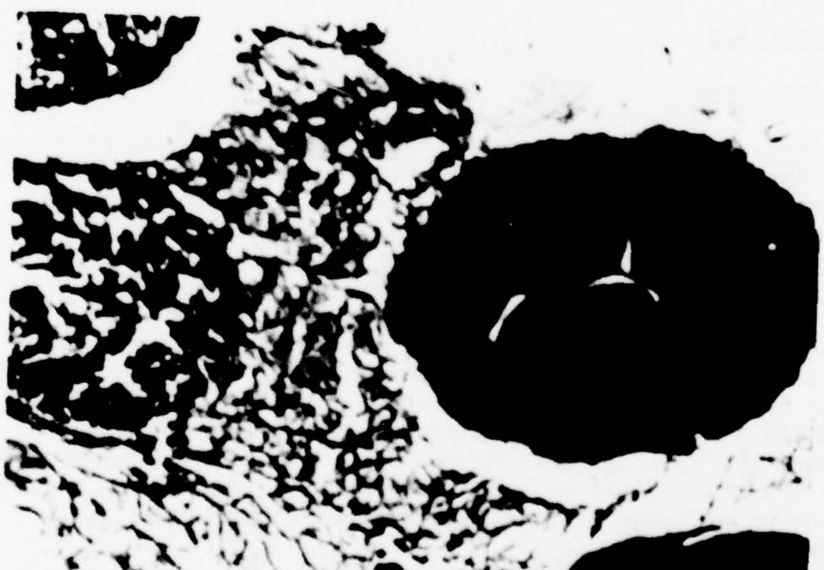


Fig. 7-18. *Corbicula fluminea* ovary and sperm present.

Differences in the rates of increase over time of these parameters, as well as shifts in their relative magnitudes are likely due, in large part, to differences in initial species composition between stations, and resulting disparate rates of successional change.

Silver and copper levels found in attached organisms (Table 7-19) varied between stations. Some variation in copper and chromium was observed at each station between sampling efforts. When the ratio "trace element:organic carbon" is taken for each station and collection effort, it is seen to decrease over time. The ratio of trace element to organic carbon was derived in order to normalize trace element data by the differing amounts of accumulated biomass on settling tubes analyzed.

Interpretation of such data is confounded by the multitude of contributing biological and physical influences - it is difficult to relate trace element uptake to analytically "available" trace element levels observed in the environment because differences in growth and species composition between racks and over time are not controlled. Also, other sources of trace elements are present, since the racks act, for example, as a collecting surface for particulate matter settling out of the water column. Dr. Horn (personal communication) suggested that if racks were removed weekly, variability of species composition might be reduced; however, the amount of growth might be so small that too little biomass might be available for analysis.

7.7 Clam Reproduction

7.7.1 Gonad Histology

Corbicula fluminea. Tissue from four C. fluminea taken during efforts 1 and 4 at the Port Chicago site were examined to determine the reproductive state and the general condition of the animals. C. fluminea is a functional hermaphrodite with eggs and sperm present simultaneously, though the two are often at different developmental stages. Therefore, in Table 7-20, male and female stages are represented separately. C. fluminea was reproductively active at the time of transplant (February 20, 1979) and 30 days later when the first group of transplant clams were removed for contaminant analysis. The ovaries were in the developing gonad "D" state at Stage 3 (see gonad description, Table 7-21). Only one of four individuals examined contained both sperm and eggs (Figure 7-18). Sperm was in the developing gonad state at Stage 2. Clams examined from Effort 1 collection were all in the 40 to 65 mm range while Effort 4 clams fell in the 20 to 40 mm range (Table 7-22).

The four individuals examined during Effort 4 on May 14, 1979 were more reproductively advanced than the Effort 1 clams. In the last collection set the ovaries had reached Stage 4 (Figure 7-19) while the testis was found to be at Stage 3. This histological examination indicates that development seems to be normal although more individuals would have to be examined for each effort and a longer time period sampled to be certain.

TABLE 7-19. TRACE ELEMENT CONTENT OF ATTACHED ORGANISMS

Area	Sampling Effort	Ag(R)	As(R)	Cd(R)	Cr(R)	Cu(R)	Hg(R)
Mare Island	3	7.8(.24)	< 1(<.01)	1(.01)	2.0(.03)	1.6(.05)	< 0.1(.003)
	4	6.9(.09)	4(.05)	1(.01)	1.2(.02)	2.0(.03)	< 0.1(.001)
Port Chicago	3	1.0(.05)	< 1(<.05)	1(.01)	2.4(.13)	2.1(.03)	< 0.1(.001)
	4	0.4(.02)	< 1(<.02)	< 1(<.02)	< 2 (.04)	3.2(.06)	< 0.1(.001)
Treasure Island	3	6.5(.03)	< 1(.004)	0.7(.002)	1.0(.004)	1.1(.004)	< 0.1(.0004)
	4	< 0.3(.001)	< 1(.004)	0.3(.001)	0.5(.04)	2.0(.01)	< 0.1(.0003)

Area	Sampling Effort	Ni(R)	PbI	PbII(R)	PbIII	Se(R)	Zn(R)
Mare Island	3	1.1(.03)	-	< 1	-	< 1	90(2.73)
	4	4.0(.05)	-	≤ 2	-	< 1	90(1.14)
Port Chicago	3	2.0(.03)	-	< 1	-	< 1	70(.89)
	4	3.5(.06)	-	< 1	-	< 1	90(1.63)
Treasure Island	3	7 (.03)	-	< 2	-	< 1	140(.58)
	4	4 (.01)	-	< 2	-	< 1	90(.30)

$R = \frac{\mu g \text{ element}}{\mu g \text{ carbon}}$

TABLE 7-20. GONADAL STAGE

DATE	AREA PORT CHICAGO	GONAD DESCRIPTION	STAGE	COMMENTS
	EFFORT 1			
	PCE1(1)		♀ 3	Eggs developing - no sperm observed.
3/13-14/79	PCE1(2)	D	3	Eggs developing - no sperm observed.
	PCE1(3)		3	Eggs developing - no sperm observed.
	PCE1(4)		3 ♂ 2	Eggs developing - sperm formation starting
	EFFORT 2			
	PCE4(1)		♀ 4 ♂ 3	Eggs further developed - sperm developing.
5/14/79	PCE4(2)		4 3	Eggs further developed - sperm developing.
	PCE4(3)	D	4 4	Eggs further developed - sperm well developed.
	PCE4(4)		4 3	Eggs further developed - sperm developing.
	Mare Island			*Corbicula* and *Mytilus* were suspended at this site.
	EFFORT 1			
	Corbicula			
	MIE1(1)		♀ 2	Eggs developing - no sperm observed.
3/8-9/79	MIE1(2)		3 ♂ 1	Eggs developing - sperm formation starting.
	MIE1(3)	D	3 1	Eggs developing - sperm formation starting.
	MIE1(4)		2	Eggs developing - no sperm observed.
	EFFORT 4			
	Corbicula			
	MIE4(1)		♀ 3 ♂ 2	Eggs developing - sperm developing.
5/07/79	MIE4(2)		3 2	Eggs developing - sperm developing.
	MIE4(3)	D	3 2	Eggs developing - sperm developing.
	MIE4(4)		3 2	Eggs developing - sperm developing.

Table 7-20. (cont.)

DATE	AREA MARE ISLAND	GONAD DESCRIPTION	STAGE	COMMENTS
	EFFORT 1			
	Mytilus			
	MIE1(1)	S	♂ 1	Sperm spent.
3/8-9/79	MIE1(2)		0	
	MIE1(3)	S	1	Sperm spent.
	MIE1(4)	S	1	Sperm spent.
	EFFORT 2			
	Mytilus			
	MIE2(1)M	R	♀ 5	Eggs ready to spawn.
5/07/79	MIE2(2)M		0	
	MIE2(3)M		♀ 1	Eggs spent.
	MIE2(4)M		0	
	<u>TREASURE ISLAND</u>			
	EFFORT 1			
	Mytilus			
	TIE1(1)M	S	♂ 1	Sperm spent
4/10-11/79	TIE1(2)M		1	Sperm spent
	TIE1(3)M		1	Sperm spent
	TIE1(4)M		1	Sperm spent

Table 7-20. (cont.)

DATE	AREA TREASURE ISLAND	GONAD DESCRIPTION	STAGE	COMMENT
	EFFORT 2			
	Mytilus			
	TIE2(1)M	S	♂ 1	Sperm spent
6/04/79	TIE2(2)M		1	Sperm spent
	TIE2(3)M		1	Sperm spent
	TIE2(4)M		3	Large amount of sperm
	<u>TREASURE ISLAND</u>			
	Mytilus			Native attached to pier.
	TIN(1)M		0	No gonad tissue
6/04/79	TIN(2)M	S	♀ 1	Some spent ovary tissue
	TIN(3)M		0	No gonad tissue
	TIN(4)M		♀ 1	Some spent ovary tissue

For more details and reference see Gonad Description Table.

TABLE 7-21. GONAD DESCRIPTION

RESTING OR SPENT GONAD

Stage 0	Inactive or neuter. This stage includes virgin animals as well as those which have completed spawning.

DEVELOPING GONAD (D)

Stage 1	Gametogenesis begins, though no ripe gametes are yet visible.
Stage 2	Ripe gametes first appear. The gonad is now about one-third of its final size.
Stage 3	There is a general increase in the mass of the gonad to about half the fully ripe condition. In area, each follicle contains approximately equal proportions of ripe developing gametes.
Stage 4	The gonad is two-thirds or more its final size. Gametogenesis is still progressing but follicles contain mainly ripe gametes.

RIPE GONAD (R)

Stage 5	Fully ripe. Early stages of gametogenesis are greatly reduced. Ova are compacted into polygonal configurations while the male gonad is distended with morphologically ripe sperm. The time between morphological and physiological ripeness may vary by up to several months under different conditions.

SPAWNING GONAD (S)

Stage 4	Active emission commences, as evidenced from the general reduction in sperm density and rounding off of the ova as pressure within the follicles is reduced.
Stage 3	The gonad is approximately half empty.
Stage 2	Further general reduction in the area occupied by the gonad is evident. The follicles are about one-third full of ripe gametes.
Stage 1	Only residual gametes remain, some of which may be undergoing cytolysis by amoebocytes.

TABLE 7-22. SIZE OF *Corbicula fluminea* TAKEN FROM SAMPLING EFFORTS 1 AND 4 FOR GONADAL EXAMINATION - RECORDED BY SIZE CLASS

Station/Effort	Size Class (mm) 20.0-39.9	40.0-65.0
Port Chicago		
Effort 1		51.5
		50.7
		50.2
		41.7
Effort 4	31.9	
	34.1	
	32.9	
	34.0	
Mare Island		
Effort 1		42.6
		42.0
	31.3	
		46.2
Effort 4	32.6	
	32.2	
	31.9	
	33.8	

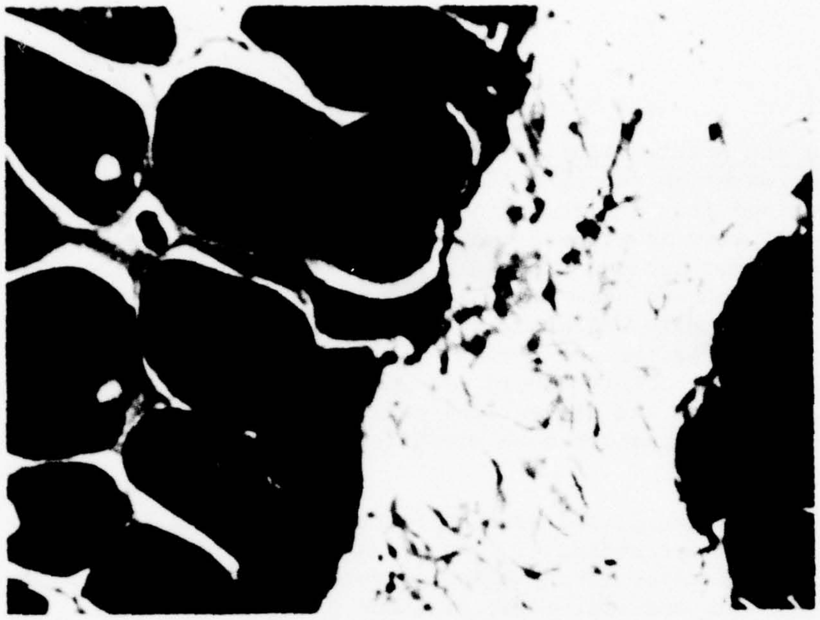


Fig. 7-19. *Corbicula fluminea* ovaries in State B, Stage 4

Fig. 7-20. *Mytilus edulis* testis in State S, Stage I

Corbicula fluminea and Mytilus edulis. At the Mare Island site, both species were transplanted on February 12, 1979. Individuals of Corbicula were examined from Efforts 1 and 4. Of the four individuals examined, two females were at Stage 3 and two at Stage 2. The males were also equally divided between Stage 0 and Stage 1. The animals examined from Effort 4 showed some development with the females reaching Stage 3 and the males reaching Stage 2. Clams collected during Effort 4 were all in the 40 to 60 mm size class (Table 7-22) while those dissected from Effort 4 were all in the 20 to 40 mm range. For some unexplained reason the larger size class of Corbicula did not survive as well as the smaller size class in the field (see Section 3.6.2).

The mussels examined at Mare Island were collected on March 8, 1979 for Effort 1 and May 7, 1979 for Effort 4. The clams examined from Effort 1 were all spent and the three in the spawning gonad (S) state were males (Figure 7-20). The one individual at Stage 0 could not be sexed. Those individuals examined from Effort 4 were in various states of spawning. One female was in Stage 5 (Figure 7-21) and one in Stage 1 (Figure 7-22). The other two individuals were in Stage 0. Mussels from Effort 1 were mostly from the greater than 70 mm size class while Effort 4 animals were distributed between size classes 45 to 60 mm, 60 to 70 mm, and greater than 70 mm.

Mytilus edulis. The mussels collected from Treasure Island from Efforts 1 and 4 were spent. In Effort 1, the four individuals were all males and in Stage 1 of the spawning gonad (S) state. In the fourth effort all the individuals were male and in Stage 1 except for one specimen which was in Stage 3. The size class collected were all in the greater than 70 mm range.

Native mussels were collected from this site on June 4, 1979 so that some comparisons might be made between transplanted mussels and those found naturally on pilings. These mussels were also spent and compared closely to the gonadal state of the transplanted individuals. The size class used represented individuals from the 45.0 to 59.9 mm, 60.0 to 69.9 mm, and greater than or equal to 70 mm size classes.

Some general comments can be made about the histological condition of the animals. The fact that the mussels were spent during early spring compared favorably to other studies on the period of gonad activity (Moore and Reish, 1969) in California. The most active period for Mytilus edulis females is from October to February; males are most active from November to May, although some males are active throughout the year. In both Corbicula and Mytilus not enough individuals were examined to really evaluate the physiological and histological state of the bivalves. At least 20 individuals should be

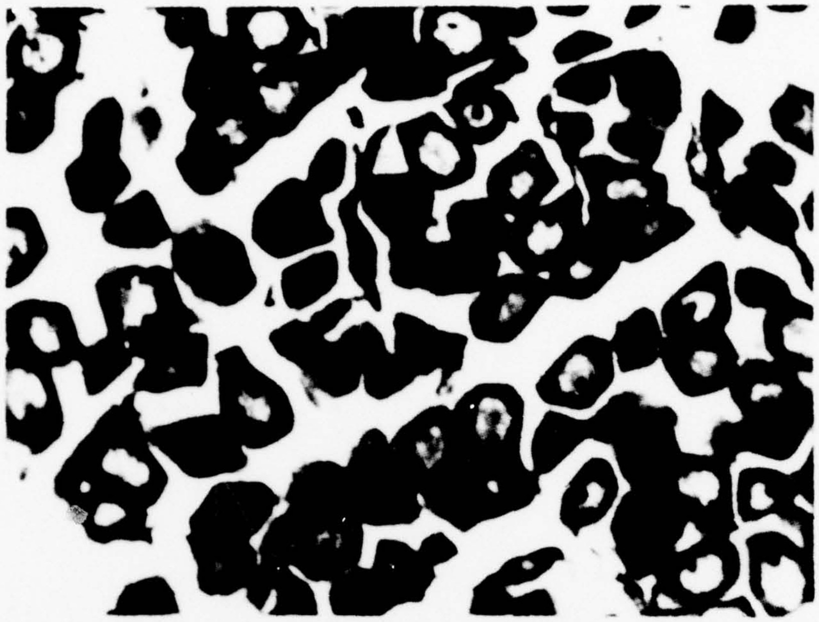


Fig.7-21. *Mytilus edulis* ovaries in State D, Stage 5

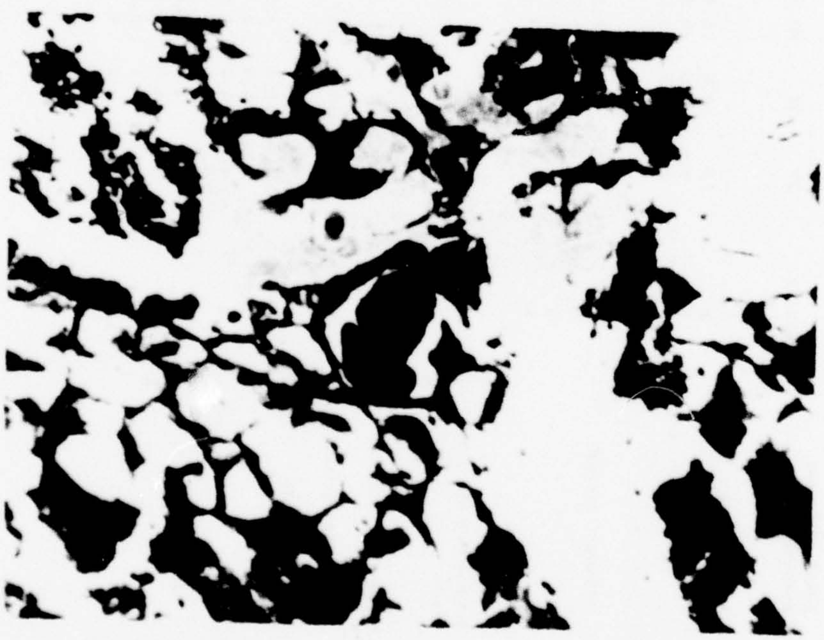


Fig. 7-22. *Mytilus edulis* ovaries in Stage S, Stage 1 or 0

TABLE 7-23.

STATUS OF BIOCHEMICAL RESERVES

Area	Effort	% Dry Weight: Glycogen 1	Glycogen 2	Glycogen $\bar{x}$	Lipid 1	Lipid 2	Lipid $\bar{x}$	Ratio Taurine/Glycine
Mytilus edulis								
Point Richmond Background	2/12/79	29	24	26.5	16	20	18	7.2
Mare Island	1	-	-	-	-	-	-	-
	2	12	10.8	11.4	16	20	18	10
	3	5.6	5.8	5.7	16	16	16	12
	4	4.1	3.7	3.9	16	19	17.5	10
Treasure Island	1	8.0	5.6	6.8	-	17	17	8.3
	2	5.6	7.2	6.4	19	22	20.5	9.0
	3	6.9	6.7	6.8	21	14	17.5	9.2
	4	4.2	4.2	4.2	18	20	19	9.5
Native Mussels from Piers		9.8	10.7	9.9	21	17	19	7.0
Corbicula fluminea								
Delta Background	2/20/79	16	16	16	14	17	15.5	5.8
Mare Island	1	-	-	-	-	-	-	-
	2	4.0	5.0	4.5	8	6	7	4
	3	4.2	5.3	4.7	8	7	7.5	3
	4	6.0	4.0	5.0	15	8	11.5	3
Port Chicago	1	3.9	3.8	3.8	10	14	12	6.1
	2	4.7	4.9	4.8	11	8	9.5	4.9
	3	4.2	4.7	4.5	16	10	13	5.2
	4	5.0	4.5	4.7	9	12	10.5	6.8

examined. As is illustrated here, in some classes all four individuals examined were of one sex. Therefore, more individuals would be needed to really assess the gonadal state. For each sample, a mean gonad index is determined by multiplying the number in each stage by the numerical ranking of the stage and dividing the sum of these products by the total of individuals in the sample. Since the number of individuals in the samples was small, the index was not established for this study.

7.7.2 Status of Biochemical Reserves

Duplicate glycogen, lipid and amino acid analyses of *Mytilus edulis* and *Corbicula fluminea* collected mid-February were performed to establish a background or pre-study point-of-reference for levels of those substances. Lack of comparable data for *M. edulis* from the vicinity necessitates interpretation of results obtained during this project by comparison with remote populations; in the case of *C. fluminea* we believe no comparable measurements have been published.

Initial (or background) content of glycogen in both bivalves species (29 for *Mytilus* and 16 for *Corbicula*) was substantially higher than that observed at any time during the remainder of the study (less than 12 for both *Mytilus* and *Corbicula*). Lipid content of *M. edulis* remained virtually unchanged, while lipid content of *C. fluminea* decreased at Mare Island but appeared stable at Port Chicago (Table 7-23).

Glycogen levels in *C. fluminea* while averaging only less than one-third of prestudy levels, did not change detectably with time at either Mare Island or Port Chicago.

Glycogen is known to be an extremely labile reserve material in many bivalves, including *M. edulis*, and changes in glycogen content are commonly observed as a response to physiological stress and as an integral component of annually cyclic reproductive metabolism.

Histological observations made on *M. edulis* gonads (see Section 7.7), while based upon a necessarily small sampling, suggest that a post-spawning population was used as a source of test organisms for this project. Assuming this to be the case, glycogen data indicates a condition of chronic stress prevailed among suspended test organisms during the period of study. However, histological and biochemical information collected over such a relatively short (in comparison with physiological cycles) period of time, makes such interpretation somewhat tenuous.

Little information on *Corbicula* physiology, including its reproductive timing, is presently available; but it is likely that it too operates at least partially on a glycogen-based metabolism. Data presented

(Table 7-23) again suggests the possibility that test organisms were coping with some energy-demanding stress. However, without data which relate glycogen, lipid, and reproductive utilization of these compounds to one another in unstressed, naturally-synchronized populations for at least one reproductive cycle, reliable conclusions cannot be drawn.

That lipid levels of test C. fluminea declined from pre-study levels, taken in conjunction with microscopic observations, also suggests the likelihood that test organisms were stressed. It is interesting to note that lipid levels were declining at Mare Island during Efforts 2 and 3 while a slight increase was observed by Effort 4. Gonadal examination also indicated that development was not proceeding at Mare Island as rapidly as at Port Chicago. Interpretative problems with this data are as discussed for glycogen data.

Recent biochemical work has suggested that the ratio of the free amino acids, taurine and glycine, may be monitored, at least in certain bivalve species, as a fairly sensitive indicator of "metabolic balance" or stress. Thus in Mercenaria mercenaria, Jeffries (1972) concluded a molar ratio of three or less indicates a "normal" condition; whereas ratios between five and seven indicate chronic stress. It is clear, on inspection of Table 7-23 that in comparison with background data, this ratio increased for both bivalves. It must be noted however, that neither the validity of the taurine/glycine ratio as an indicator of stress in the two species used here, nor the degree to which "background" data presented here is representative of natural populations has been established.

7.8 Faunal Core Samples

Core samples for enumeration of infauna were collected at the beginning and end of the study period to determine if changes of relative abundances or species composition had occurred; results are presented in Appendix A. The greatest variety of fauna was found at Treasure Island. Four species of polychaetes, two molluscs, and several nematodes were found. At Mare Island, two species, each, of polychaetes and amphipods were found, including harpacticoid copepods and nematodes. Infauna found at Port Chicago included only nematodes and two harpacticoids. Examination of the data indicates that gross changes of measured infaunal characteristics did not take place during the study period.

7.9 Sediment - Particle Size Analysis

At the beginning and end of the study period, a sediment sample was collected from each sampling station for particle size analysis. It is apparent that at all three sampling sites the major constituents of the sediments are silts and clays. Inspection of the particle size distribution of sediment sample collected during the first and last sampling efforts suggest that no appreciable change in the percentages of sand and silt/clay fraction occurred between sampling efforts.

7.10 Bivalve Laboratory Experiments

Prior to the beginning of field sampling for this pilot study, an attempt was made to evaluate the suitability of the river clam *Corbicula fluminea* as a test organism. A review of available literature indicated that little is known about the natural biology and ecology of this species; information on the ability of this bivalve to concentrate trace elements and PCBs is not abundant. Following consultation with the Corps of Engineers, preliminary laboratory experiments were conducted in an attempt to gain information on: (1) the tolerance of this bivalve to salinities anticipated at the Suisun Bay (Port Chicago) and Carquinez Strait (Mare Island) sampling sites; and (2) the ability of *Corbicula* to concentrate trace elements in the body tissues. The design, procedure and results of these experiments are discussed below.

7.10.1 Metal Uptake

An experiment was conducted to determine whether or not *Corbicula fluminea* would respond under laboratory conditions to increased ambient levels of three trace elements. Copper, cadmium and zinc were selected on the basis of body burden data obtained by the California Department of Fish & Game (1977) for specimens from the Scaramento River Delta.

Corbicula fluminea were obtained from Panfili's Bait Shop in Antioch on February 12, 1979; water from the Sacramento River was collected at the same time to serve as test medium. The clams were randomly assigned to aquaria containing river water and allowed to acclimate for two weeks. Additions of 0, 2.5, 5.0 and 10 micrograms per liter of copper, cadmium and zinc were then made; each of these treatments was replicated once.

Five randomly selected clams were removed immediately from each aquaria (Day #0 sample, page A-41, Appendix A) and frozen for later anlaysis. On the 10th day of the experiment, five more individuals were picked randomly (Day #10 sample, page A-41, Appendix A). Prior to analysis,

each group of five clams was homogenized to form one composite sample. Each composite sample was analyzed for cadmium, copper and zinc. Results of these anlyses are presented in Table A-35 on page A-41, Appendix A.

The results of the metal uptake experiment were inconclusive. Although none of the metals were taken up during the experimental period, it could not be concluded that this bivalve would not accumulate trace elements under field conditions. The period of exposure time was apparently too short to allow substantial amounts of metals to accumulate in the tissues via metabolic processes.

7.10.2 Salinity Tolerance

In order to evaluate the salinity tolerance of *C. fluminea*, a short-term experiment in which the bivalves were exposed to selected salinity concentrations was conducted. Four treatment tanks were used for the experiment. One tank served as a control and the others were used to expose the bivalves to the following salinities: 10, 15 and 30 ppt.

A group of ten clams was installed in each tank. During the experiment, the water in the tanks was constantly aerated and the bivalves were periodically fed with *Selenastrum capricornutum*, a freshwater green alga. After five days of exposure, no mortality was observed in any of the tanks. However, observations on behavior made during this time suggested that the clams in the treatment tanks were neither respiring nor feeding at the same rate as the control group. In the control tank an abundance of feces and pseudofeces were present, indicating that the clams had been filtering the water. No fecal material was observed in any of the treatment tanks. After eight days, substantial mortality had occurred in the treatment tanks. The following percentage mortality was observed: 30 ppt - 60 percent; 15 ppt - 70 percent; 10 ppt - 60 percent; control - 0 percent.

The results of the salinity exposure tests indicated that *Corbicula fluminea* may be intolerant to even short-term exposure to salinities as low as 10 parts-per-thousand. It is further suggested that the salinity threshold limit for this bivalve is between 0 and 10 parts-per-thousand. This fact may limit the usage of this clam for bioassay purposes to the upper Delta regions. However, more detailed laboratory experiments should be conducted on salinity tolerance and metal uptake before *Corbicula fluminea* is used extensively as a test organism for San Francisco Bay.

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APPENDIX A

PILOT WATER QUALITY MONITORING STUDY
SAN FRANCISCO BAY AND DELTA

ERRATA: Pages A-31 and A-32 have been removed.

TABLE A-1. *STUDENT T VALUES FOR TRACE ELEMENTS IN BIVALVE TISSUES AS COMPARED TO MEAN BACKGROUND LEVELS*

Species/Location	Sampling Effort	Trace Elements									
		Ag	As	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn
Mytilus edulis Mare Island	1	-0.226	-0.577	5.171	13.880*	-2.023	-0.081	-5.715	1.735	1.292	0.579
	2	-0.045	-0.286	5.443	33.476*	-1.734	-1.388	-3.538	0.918	-0.145	--
	3	-0.725	-0.859	8.437	74.301*	-1.950	1.388	-3.538	0.816	-0.670	-1.737
	4	-0.226	-1.443	-0.289	90.630*	-1.662	-0.816	-2.177	2.245	-0.874	-2.316
Mytilus edulis Treasure Island	†	-0.544	-1.003	2.450	0.725	-2.370	-2.449	-4.898	2.041	-0.729	-6.369
	2	-0.589	-1.002	13.336*	5.715	-2.182	0.816	-6.531	2.653	-1.152	-4.053
	3	1.134	-1.418	-0.272	L.A.	-1.878	1.632	4.626	1.530	-1.326	-4.053
	4	-0.589	-1.203	-2.449	1.632	-2.753	-0.572	9.525	-0.204	-1.749	-4.632
	††	-0.226	-1.346	22.317*	45.723*	-1.517	-0.489	-4.206	0.612	-1.764	-1.158
Corbicula fluminea Mare Island	1	-0.494	--	1.632	0	3.073	4.830	-0.612	2.857	-4.082	-0.097
	2	-0.386	--	--	-1.265	-1.844	5.103	-0.918	0.714	-2.916	-0.579
	3	-0.580	--	-2.177	-1.538	-1.854	3.742	-0.714	1.326	-4.199	-1.158
	4	0.666	--	4.354	-6.531	-1.825	1.973	0.102	2.143	-4.141	-0.965
Corbicula fluminea Port Chicago	1	-0.064	--	4.354	-0.816	-0.960	9.049	-1.326	-1.123	-4.665	-1.061
	2	-0.279	--	9.797	0.816	-0.480	3.742	-0.765	3.878	-2.916	0.096
	3	0.043	--	15.241*	6.804	-1.248	5.103	-0.051	1.735	-4.082	0.193
	4	-0.128	--	12.519	8.437	-1.729	6.197	0.510	1.837	-2.916	-0.386

* = indicates difference at 95% level ($P < 0.05$).

† = M. edulis obtained from Point Richmond area. These bivalves are considered as second out of background trace metal tissue data.

†† = M. edulis obtained from suspended racks at Treasure Island. Concurrent water quality samples not taken.

L.A. - Laboratory accident.

TABLE A-2. MARE ISLAND: SUMMARY OF WATER QUALITY ASSAYS FOR THE FOUR SAMPLING DATES

		Trace Elements												
		Ag	As	Cd	Cr	Cu	Hg	Ni	Pb	Pb III	Se	Zn	NO_3	NH_3
Water Column (µg/L)	$\bar{x}$	2.38	9.4	0.41	3.8	5.53	0.95	21.0		11.08	6.60	32.75		
	s^2	0.25	10.64	0.038	7.42	5.42	0.25	12.0		113.09	4.19	56.92		
	S.E.	0.25	1.63	0.098	1.36	1.16	0.25	1.73		5.32	1.02	3.77		
	C.V.	21.02	34.70	48.15	71.68	42.15	52.63	16.49		96.02	31.00	23.04		
	LCI	1.58	4.21	0.095	< 0	1.82	0.15	15.49		< 0	3.34	20.75		
	UCI	3.17	14.59	0.72	8.13	9.23	1.75	26.51		27.99	9.86	44.75		
Settled Particu-lates (µg/mg)	$\bar{x}$	2.63	12.85	1.55	158.0	105.5	0.68 *	76.75	42.5		2.13	137.5	2.4	
	s^2	0.25	35.16	1.12	2,576.0	787.67	0.003*	516.25	75.0		3.68	1,825.0	1.63	
	S.E.	0.25	2.96	0.53	25.38	14.03	0.03 *	11.36	4.33		0.96	21.36	0.64	
	C.V.	19.02	46.14	68.38	32.12	26.60	7.64 *	29.60	20.38		90.31	31.07	53.25	
	LCI	1.83	3.42	< 0	77.25	60.85	0.55 *	41.60	28.72		< 0	69.53	0.37	
	UCI	3.42	22.28	3.24	238.75	150.15	0.81 *	112.9	56.28		5.18	205.47	4.43	
Bottom Sediments (µg/mg)	$\bar{x}$	2.68	13.5	2.28		119.0	0.75	80.25	61.25		1.85	152.5	8.5	470.0
	s^2	2.51	51.0	2.45		1,188.67	0.03	146.92	182.25		0.34	291.67	5.67	71,066.67
	S.E.	0.79	3.57	0.78		17.24	0.09	6.06	6.75		0.29	8.54	1.19	133.29
	C.V.	59.22	52.9	68.79		28.98	24.86	15.10	22.04		31.36	11.2	28.01	56.72
	LCI	1.66	2.14	< 0		64.15	0.45	60.97	39.77		0.93	125.33	4.71	45.87
	UCI	5.2	24.86	4.76		173.85	1.04	99.53	82.73		2.77	179.67	12.29	894.13

$\bar{x}$ = Mean.
s^2 = Variance.
S.E. = Standard error.
C.V. = Coefficient of variation.
LCI = 95% Lower confidence interval.
UCI = 95% Upper confidence interval.
* = Where N=3; for remaining elements, N=4.

Table A - 2. Mare Island (cont.)

		Ag	As	Cd	Cr	Cu	Hg	Ni	Pb	Pb III	Se	Zn	NO_3	NH_3
		Trace Elements												
Mytilus edulis (μg/mg)	$\bar{x}$	1.73	8.5	2.83	7.4	14.5	0.47	3.33	3.4		10.6	285.0		
	s^2	0.42	11.67	1.78	18.91	5.67	0.02	0.29	0.45		5.31	566.67		
	S.E.	0.32	1.71	0.67	2.17	1.19	0.07	0.27	0.33		1.15	11.9		
	C.V.	37.38	40.18	47.17	58.76	16.42	31.12	16.17	19.66		21.73	8.35		
	CLI	0.7	3.07	0.7	0.48	10.71	0.24	2.47	2.34		6.93	247.13		
	UCI	2.75	13.93	4.95	14.32	18.29	0.71	4.18	4.46		14.27	322.87		
Corbicula fluminea (μg/mg)	$\bar{x}$	1.55	10.78	1.83	3.78	22.68	0.31	4.0	2.50		10.68	280.0		
	s^2	0.36	7.4	0.91	1.63	601.22	0.01	0.67	0.29		2.41	246.67		
	S.E.	0.3	1.36	0.48	0.64	12.26	0.04	0.41	0.27		0.78	24.83		
	C.V.	38.53	25.25	52.25	33.81	108.14	28.25	20.41	21.42		14.54	17.74		
	LCI	0.6	6.45	0.31	1.74	< 0	0.17	2.7	1.65		8.21	200.98		
	UCI	2.5	15.1	3.34	5.81	61.69	0.45	5.3	3.35		13.14	359.02		
Total Suspended Parti- culates (μg/mg)	$\bar{x}$	4.88	18.58	14.98	280.25	421.75	3.10*	495.5	173.5		100.48	700.0		
	s^2	1.18	36.05	67.61	11,446.25	6,041.58	3.51*	35,201.0	10,763.67		10,993.05	24,466.67		
	S.E.	0.54	3.0	4.11	53.49	38.86	1.08*	93.81	51.87		52.42	78.21		
	C.V.	22.26	32.32	54.91	38.18	18.43	60.44*	37.86	59.8		104.35	22.35		
	LCI	3.15	9.02	1.89	110.03	298.09	< 0 *	197.0	8.44		< 0	451.14		
	UCI	6.6	28.13	28.06	450.47	545.41	7.75*	794.0	338.56		267.29	948.86		

$\bar{x}$ = Mean.
s^2 = Variance.
S.E. = Standard error.
C.V. = Coefficient of variation.
LCI = 95% Lower confidence interval.
UCI = 95% Upper confidence interval.
* = Where N=3; for remaining elements, N=4.

TABLE A-3 TREASURE ISLAND: SUMMARY OF WATER QUALITY ASSAYS FOR THE FOUR SAMPLING DATES

		Trace Elements											
		Ag	As	Cd	Cr	Cu	Hg	Ni	Pb	PbIII	Se	Zn	NO_3*
Water Column (µg/L)	$\bar{x}$	1.85	7.33	0.64	5.38	6.73	0.36	40.75		20.75	7.68	42.75	
	s^2	0.22	7.82	0.04	0.91	5.34	0.01	152.25		39.58	14.54	41.58	
	S.E.	0.23	1.40	0.10	0.48	1.16	0.08	6.17		3.15	1.91	3.22	
	C.V.	25.16	38.18	31.07	17.74	34.37	47.16	30.28		30.32	49.68	15.08	
	LCI	1.11	2.88	0.32	3.86	3.05	0.09	21.12		10.74	1.61	32.49	
	UCI	2.58	11.77	0.96	6.89	10.40	0.63	60.38		30.76	13.74	53.01	
Settled Parti-culates (µg/mg)	$\bar{x}$	1.15	8.48	1.68	114.0	175.0	0.70	92.25	30.50		2.78	192.50	
	s^2	0.43	9.65	0.21	410.67	966.67	0.02	30.92	75.00		0.68	491.67	
	S.E.	0.33	1.55	0.23	10.13	15.55	0.07	2.78	4.33		0.41	11.09	
	C.V.	47.02	36.65	27.30	17.78	17.77	20.14	6.03	28.39		29.77	11.52	
	LCI	0.11	3.53	0.95	81.76	125.53	0.48	83.40	16.72		1.46	157.22	
	UCI	2.19	13.42	2.40	146.24	224.47	0.93	101.10	44.28		4.09	227.78	
Bottom Sediments (µg/mg)	$\bar{x}$	1.85	8.73	1.93	126.25	150.00	0.54	85.25	68.50		2.95	232.50	42.00
	s^2	4.16	12.97	0.68	1,356.25	466.67	0.02	311.58	449.00		0.62	1,158.33	1,519.00
	S.E.	1.02	1.80	0.41	18.41	10.80	0.07	8.83	10.59		0.39	17.02	22.50
	C.V.	110.29	41.28	42.71	29.17	14.40	27.78	20.71	30.93		26.62	14.64	92.80
	LCI	< 0	3.00	0.62	67.66	115.63	0.30	57.17	34.79		1.70	178.35	< 0
	UCI	5.10	14.45	3.23	184.84	184.37	0.78	113.33	102.21		4.20	286.65	138.83

$\bar{x}$ = Mean.
s^2 = Variance.
S.E. = Standard error.
C.V. = Coefficient of variation.
LCI = 95% Lower confidence interval.
UCI = 95% Upper confidence interval.
* = Where N=3; for remaining elements, N=4.

Table A-3. Treasure Island (cont.)

		Ag	As	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn	NO_3
Mytilus	$\bar{X}$	2.25	5.33	4.58	3.07*	11.18	0.54	4.98	3.23	3.73	230.0	
edulis	s^2	3.26	1.64	14.59	8.90*	52.38	0.02	7.83	1.14	4.44	1,400.0	
(µg/mg)	S.E.	0.9	0.64	1.91	1.72*	3.62	0.07	1.40	0.53	1.05	18.71	
	C.V.	80.29	24.02	83.49	97.30*	64.76	24.10	56.24	33.05	56.58	16.27	
	LCI	< 0	3.29	< 0	< 0 *	< 0	0.33	0.52	1.53	0.37	170.47	
	UCI	5.12	7.36	10.65	10.48*	22.69	0.75	9.43	4.92	7.08	289.53	
Total	$\bar{X}$	29.75	29.05	13.00	436.0	555.0	4.60	450.00	309.50	13.03	417.50	
Suspended	s^2	13.10	15.21	13.78	43,090.67	3,100.0	1.22	10,400.0	707.67	7.42	1,558.33	
Parti-	S.E.	1.81	1.95	1.86	103.79	27.84	0.55	50.99	13.30	1.36	19.74	
culates	C.V.	12.16	13.43	28.55	47.61	10.03	24.01	22.66	8.60	20.92	9.46	
(µg/mg)	LCI	23.99	22.85	7.09	105.74	466.42	2.84	287.75	267.18	8.69	354.69	
	UCI	35.51	35.25	18.91	766.26	643.58	6.36	612.25	351.82	17.36	480.31	

$\bar{X}$ = Mean.
s^2 = Variance.
S.E. = Standard error.
C.V. = Coefficient of variation.
LCI = 95% Lower confidence interval.
UCI = 95% Upper confidence interval.
* = Where N=3; for remaining elements, N=4.

TABLE A-4. PORT CHICAGO: SUMMARY OF WATER QUALITY ASSAY FOR THE FOUR SAMPLING PERIODS

		Trace Element														
		Ag	As	Cd	Cr	Cu	Hg	Ni	Pb	PbI	PbII	PbIII	Se	Zn	NO_3	NH_3
Water Column (µg/L)	$\bar{X}$	2.48	11.75	0.93	1.78	8.78	0.72	27.5		6.45	6.45	77.25	7.18	46.0		
	s^2	2.01	26.25	0.12	0.49	53.2	0.14	107.67		5.84	5.84	794.25	1.68	983.33		
	S.E.	0.71	2.56	0.18	0.35	3.65	0.19	5.19		1.21	1.21	14.09	0.65	15.68		
	C.V.	57.27	43.6	37.84	39.4	83.12	52.26	37.73		37.48	37.48	36.48	18.09	68.17		
	LCI	0.22	3.6	0.37	0.66	< 0	0.12	10.99		2.6	2.6	32.41	5.11	< 0		
	UCI	4.73	19.9	1.48	2.89	20.38	1.32	44.01		10.3	10.3	122.09	9.24	95.89		
Settled Parti-culates (µg/mg)	$\bar{X}$	3.6	7.15	1.75	140.0	120.0	0.75	65.25	42.0				9.05	440.0		
	s^2	3.71	0.87	0.07	600.0	333.33	0.11	378.25	114.67				6.4	4,200.0		
	S.E.	0.96	0.47	0.13	12.25	9.13	0.17	9.72	5.35				1.27	32.4		
	C.V.	53.53	13.05	15.12	17.5	15.21	44.01	29.81	25.5				27.96	14.73		
	LCI	0.53	5.67	1.33	101.03	90.95	0.23	34.31	24.96				5.02	336.89		
	UCI	6.67	8.63	2.17	178.97	149.05	1.28	96.19	59.04				13.08	543.11		
Bottom Sediments (µg/mg)	$\bar{X}$	3.65	11.75	5.63	278.33*	152.5	1.05	104.0	96.5				5.35	365.0	29.5	280.0
	s^2	0.74	4.25	2.18	21,858.33*	491.67	0.03	50.67	340.33				38.92	2,833.33	53.67	19,000.0
	S.E.	0.43	1.03	0.74	85.36*	11.09	0.09	3.56	9.22				2.69	26.61	3.66	68.92
	C.V.	23.51	17.55	26.22	53.12*	14.54	16.5	6.84	19.12				100.51	14.58	24.83	49.23
	LCI	2.28	8.47	3.28	< 0 *	117.22	0.78	92.68	67.15				< 0	280.31	17.84	60.7
	UCI	5.02	15.03	7.97	645.63*	187.78	1.32	115.32	125.85				13.91	449.69	41.16	499.3

$\bar{X}$ = Mean.
s^2 = Variance.
S.E. = Standard error.
C.V. = Coefficient of variation.
LCI = 95% Lower confidence interval.
UCI = 95% Upper confidence interval.
* = Where N=3.

Table A - 4 Port Chicago (cont.)

		Trace Element														
		Ag	As	Cd	Cr	Cu	Hg	Ni	Pb	PbI	PbII	PbIII	Se	Zn	NO_3	NH_3
Corbicula fluminea (µg/mg)	$\bar{x}$	3.50	12.2	4.25	6.0	15.5	0.49	4.2	3.0				10.25	320.0		
	s^2	0.39	4.56	2.92	2.73	29.67	0.03	2.49	1.38				1.58	3,533.33		
	S.E.	0.31	1.07	0.85	0.83	2.72	0.08	0.79	0.59				0.63	29.72		
	C.V.	17.92	17.5	40.18	27.55	35.14	33.97	37.55	39.16				12.28	18.58		
	LCI	2.5	8.8	1.53	3.37	6.83	0.22	1.69	1.13				8.25	225.43		
	UCI	4.5	15.6	6.97	8.63	24.17	0.75	6.71	4.87				12.25	414.57		
Total Suspended Parti- culates (µg/mg)	$\bar{x}$	6.78	20.4	16.90	201.75	517.5	3.75	424.5	146.75				23.73	597.5		
	s^2	1.81	23.61	24.08	9,054.25	3,691.67	1.38	8,654.33	657.58				14.75	1,225.0		
	S.E.	0.67	2.43	2.45	47.58	30.38	0.59	46.51	12.82				1.92	17.5		
	C.V.	19.85	23.82	19.04	47.16	11.74	31.29	21.91	17.47				16.19	5.86		
	LCI	4.64	12.67	9.09	50.36	420.83	1.88	276.49	105.95				17.61	541.82		
	UCI	8.91	28.13	24.71	353.14	614.17	5.62	572.51	187.55				29.84	653.19		

$\bar{x}$ = Mean.
s^2 = Variance.
S.E. = Standard error.
C.V. = Coefficient of variation.
LCI = 95% Lower confidence interval.
UCI = 95% Upper confidence interval.

TABLE A-5. LABORATORY REPORT OF ANALYSIS, MARE ISLAND SAMPLING EFFORT NO. 1, 24-HOUR SAMPLING.

Time	°C	Salinity PPT	D.O. PPM	Lab.No.	Settleable Solids mL/L	Nonfilterable Residue mg/L	Lab.No.	Ammonia mg/L	Nitrate mg/L	Lab.No.	Turbidity NTU
3/8/79											
1900	13.1	3.9	8.8	6183	<0.2	52	6203	0.33	0.69	6227	15
2000	13.9	3.5	9.0	6184	<0.2	52	6204	0.28	0.86	6228	15
2100	12.9	3.6	9.1	6185	<0.2	39	6205	0.25	0.96	6229	25
2200	12.7	9.0	8.8	6186	<0.2	84	6206	0.28	0.65	6230	25
2300	12.5	10.5	8.8	6187	<0.2	69	6207	0.27	0.56	6231	35
3/9/79											
0000	12.7	9.2	8.5	6188	<0.2	60	6208	0.23	0.51	6232	25
0100	12.2	10.3	8.9	6189	<0.2	40	6209	0.27	0.54	6233	40
0200	12.1	10.8	9.0	6190	<0.2	74	6210	0.28	0.51	6234	35
0300	12.2	9.3	8.7	6191	<0.2	55	6211	0.28	0.48	6235	10
0400	12.2	7.2	8.6	6192	<0.2	29	6212	0.32	0.54	6236	17
0500	12.4	6.9	7.7	6193	<0.2	30	6213	0.39	0.48	6237	14
0600	12.3	7.5	9.0	6194	<0.2	31	6214	0.34	0.49	6238	15
0700	12.3	8.2	9.4	6195	<0.2	45	6215	0.26	0.62	6239	30
0800	12.3	7.0	9.5	6196	<0.2	66	6216	0.23	0.73	6240	13
0900	12.4	8.9	9.2	6197	<0.2	33	6217	0.23	0.59	6241	60
1000	12.8	9.7	8.7	6198	<0.2	42	6218	0.26	0.63	6242	20

TABLE A-5. (cont.)

Time	°C	Salinity PPT	D.O. PPM	Lab.No.	Settleable Solids mL/L	Nonfilterable Residue mg/L	Lab.No.	Ammonia mg/L	Nitrate mg/L	Lab.No.	Turbidity NTU
3/9/79											
1100	12.6	10.5	8.7	6199	<0.2	750	6219	0.30	0.74	6243	30
1200	12.5	13.0	8.5	6200	<0.2	91	6220	0.25	0.63	6244	30
1300	12.6	11.5	8.8	6201	<0.2	86	6221	0.31	0.62	6245	30
1400	13.0	9.0	8.9	6202	<0.2	46	6222	0.33	0.65	6246	20
1500	13.2	8.1	8.9	6179	<0.1	38	6223	0.76	0.67	6247	20
1600	13.5	7.2	8.8	6180	<0.1	80	6224	0.60	0.72	6248	30
1700*	14.2	6.8	8.2	6181	<0.1	54	6225	0.62	0.67	6249	30
1800	13.0	7.0	9.5	6182	0.15	220	6226	0.64	0.73	6250	80

* Surface Sample

TABLE A-6. LABORATORY REPORT OF ANALYSIS, TREASURE ISLAND SAMPLING EFFORT NO. 1, 24-HOUR SAMPLING.

Time	°C	Salinity ppt	D.O. ppm	Lab. No.	Nonfiltrable Residue mg/L	Settleable Solids mL/L	Lab. No.	Ammonia mg/L	Nitrate mg/L	Lab. No.	Turbidity NTU
4/10/79											
1245	13.2	25	6.1	6428	39	< 0.1	6452	0.48	0.22	6476	10
1345	13.1	25	8.6	6429	37	< 0.1	6453	0.14	0.18	6477	14
1445	13.0	23.5	6.6	6430	21	< 0.1	6454	0.12	0.18	6478	15
1545	13.2	26.8	8.7	6431	76	< 0.1	6455	0.12	0.19	6479	17
1645	13.2	26.8	7.8	6432	66	< 0.1	6456	0.15	0.17	6480	18
1745	13.2	26.8	8.6	6433	31	< 0.1	6457	0.16	0.20	6481	16
1845	13.1	27.0	8.5	6434	34	< 0.1	6458	0.15	0.18	6482	16
1945	13.0	27.0	8.5	6435	31	< 0.1	6459	0.13	0.14	6483	16
2045	13.0	26.5	8.4	6436	40	< 0.1	6460	0.15	0.17	6484	19
2145	12.9	27.0	7.6	6437	38	< 0.1	6461	0.18	0.17	6485	18
2245	12.0	29.5	7.2	6438	33	< 0.1	6462	0.12	0.17	6486	17
2345	12.5	28.5	8.0	6439	37	< 0.1	6463	0.10	0.16	6487	24
4/11/79											
0045	13.0	26.2	8.1	6440	48	< 0.1	6464	0.13	0.18	6488	21
0145	13.0	27.0	7.9	6441	41	< 0.1	6465	0.15	0.15	6489	18
0245	13.0	27.0	7.8	6442	41	< 0.1	6466	0.10	0.16	6490	26

TABLE A-6. (cont.)

TIME	°C	Salinity ppt	D.O. ppm	Lab. No.	Nonfiltrable Residue mg/L	Settleable Solids ml/L	Lab. No.	Ammonia mg/L	Nitrate mg/L	Lab. No.	Turbidity NTU
0345	13.0	27.0	7.9	6443	52	< 0.1	6467	0.10	0.20	6491	26
0445	13.1	25.8	7.7	6444	28	< 0.1	6468	0.10	0.17	6492	30
0545	13.0	26.0	7.8	6445	33	< 0.1	6469	0.08	0.17	6493	33
0645	12.8	26.8	7.7	6446	34	< 0.1	6470	0.14	0.19	6494	24
0745	12.7	25.4	7.2	6447	38	< 0.1	6471	0.08	0.17	6495	27
0845	12.7	27.0	7.7	6448	39	< 0.1	6472	0.07	0.16	6496	26
0945	12.5	26.5	7.9	6449	65	< 0.1	6473	0.10	0.15	6497	31
1045	12.0	26.5	7.4	6450	45	< 0.1	6474	0.77	0.17	6498	23
1145	12.4	27.2	7.6	6451	36	< 0.1	6475	0.84	0.16	6499	26

TABLE A-7. LABORATORY REPORT OF ANALYSIS, PORT CHICAGO SAMPLING EFFORT NO. 1, 24-HOUR SAMPLING.

Time	°C	Salinity PPT	D.O. PPM	Lab.No.	Settleable Solids ml/L	Nonfilterable Residue mg/L	Lab.No.	Ammonia mg/L	Nitrate mg/L	Lab.No.	Turbidity NTU
3/13/79											
1430	13.5	1.5	9.2	6283	<0.1	80	6259	0.49	0.86	6307	48
1530	12.3	1.7	9.1	6284	<0.1	72	6260	0.46	0.81	6308	45
1630	13.5	0.5	9.4	6285	<0.1	83	6261	0.48	0.92	6309	53
1730	13.4	0.0	9.4	6286	<0.1	130	6262	0.39	0.85	6310	64
1830	13.5	0.0	9.6	6287	0.1	140	6263	0.41	0.74	6311	64
1930	13.4	0.0	9.6	6288	<0.1	90	6264	0.35	0.78	6312	61
2030	13.3	0.0	9.5	6289	0.1	96	6265	0.50	0.76	6313	29
2130	13.3	0.0	9.3	6290	<0.1	73	6266	0.40	0.76	6314	52
2230	13.5	0.0	9.6	6201	<0.1	55	6267	0.26	0.80	6315	37
2330	13.5	0.0	9.7	6292	<0.1	36	6268	0.29	0.67	6316	35
3/14/79											
0030	13.4	0.0	9.8	6293	<0.1	53	6269	0.30	0.73	6317	58
0130	13.2	0.0	9.8	6294	<0.1	64	6270	0.36	0.72	6318	50
0230	13.2	0.0	9.7	6295	<0.1	67	6271	0.28	0.74	6319	58
0330	13.2	0.0	9.2	6296	<0.1	58	6272	0.27	0.73	6320	53
0430	13.2	0.0	9.6	6297	<0.1	64	6273	0.28	0.72	6321	46
0530	13.2	0.0	9.5	6298	<0.1	62	6274	0.24	0.89	6322	38

TABLE A - 7 . (cont.)

Time	°C	Salinity PPT	D.O. PPM	Lab.No.	Settleable Solids mL/L	Nonfilterable Residue mg/L	Lab.No.	Ammonia mg/L	Nitrate mg/L	Lab.No.	Turbidity NTU
3/14/79											
0630	13.3	0.0	9.6	6299	<0.1	90	6275	0.27	0.78	6323	47
0730	13.3	0.0	9.5	6300	<0.1	81	6276	0.26	0.77	6324	51
0830	13.2	0.0	9.5	6301	<0.1	64	6277	0.26	0.72	6325	51
0930*	13.3	0.0	9.4	6302	<0.1	47	6278	0.25	0.66	6326	52
1030	13.5	0.0	9.5	6303	<0.1	44	6279	0.28	0.67	6327	37
1130	13.6	0.0	9.7	6304	<0.1	32	6280	0.26	0.65	6328	32
1230	13.5	0.0	9.7	5305	0.1	45	6281	0.26	0.70	6329	46
1330	13.4	0.0	9.7	6306	<0.1	32	6282	0.26	0.77	6330	46

*Surface Sample

TABLE A-8. WATER COLUMN ANALYSIS.

Site	Effort	Date	Time	Temp. °C	Salinity ppt	D.O. ppm	Settleable Solids (ml/L)	Non-filterable Residue (mg/L)	Ammonia (mg/L)	Nitrate (mg/L)	Turbidity (NTU)
Mare Island	2	3/23/79	1400	15.1	7.9	8.6	< 0.1	61	0.25	0.66	35
	3	4/06/79	1345	15.0	9.0	8.6	1.0	43	0.10	0.38	23
	4	5/07/79	1430	15.5	15.5	8.5	< 0.1	71	< 0.05	0.68	34
Port Chicago	2	3/30/79	0930	15.0	0.0	8.8	< 0.1	6.7	< 0.03	0.73	110
	3	4/13/79	1130	15.5	0.2	8.8	< 0.1	29	0.03	0.85	9.0
	4	5/14/79	1100	19.0	4.5	8.4	0.3	220	0.25	0.73	280
Treasure Island	2	4/24/79	1530	14.0	26.2	---	< 0.1	41	0.22	0.24	7.7
	3	5/09/79	1500	14.5	25.0	8.2	< 0.1	18	0.20	0.21	8.9
	4	6/04/79	1330	17.6	24.2	7.2	< 0.1	20	0.72	0.30	10

TABLE A-9. REPORT OF PCB ANALYSIS ON BOTTOM SEDIMENTS

Location	Date	ppm Dry Weight
Mare Island	3/09/79	< 0.1
	3/23/79	< 0.1
	4/06/79	< 0.1
	5/07/79	
Port Chicago	3/14/79	< 0.1
	3/30/79	< 0.1
	4/13/79	< 0.1
	5/14/79	
Treasure Island	4/11/79	0.1
	4/24/79	0.01<level≤0.09
	5/09/79	0.01<level≤0.09
	6/04/79	

TABLE A-10

P C B   A N A L Y S I S

Site	Effort	Date	Water Column $\bar{X}$(ng/L)	Suspended Particulates (ng/kg) $\geq 4\mu$	Suspended Particulates (ng/kg) Pass 1μ-4μ	Suspended Particulates (ng/kg) 0.07μ-1μ	Settled Particulates (ng/kg)	Artificial Substrate (ng)	Test Organisms (mg/kg) *M. edulis*	Test Organisms (mg/kg) *C. fluminea*
Mare Island	1	3/09/79	2.5	0.0025	≤0.0023	≤0.0023	< 0.1	< 0.1	< 1	< 1
	2	3/23/79	5.0	<0.0025	0.0025	0.0025	< 0.1	< 0.1	< 1	< 1
	3	4/06/79	3.8	<0.0025	≤0.0023	≤0.0023	< 0.1	< 0.1	< 1	< 1
	4	5/07/79	5.0	<0.0025	<0.0025	<0.0025	< 0.1	< 0.1		
Port Chicago	1	3/13/79	2.5	0.0025	0.015	<0.0025	< 0.1	< 0.1	< 1	< 1
	2	3/20/79	3.8	0.0025	0.0025	≤0.0023	< 0.1	< 0.1	< 1	< 1
	3	4/13/79	2.5	≤0.0023	≤0.0023	≤0.0023	< 0.1	< 0.1	< 1	< 1
	4	5/14/79	2.5	<0.0025	<0.0025	<0.0025	< 0.1	< 0.1	< 1	< 1
Treasure Island	1	4/10/79	< 2.5	<0.0023	0.0075	≤0.0023	< 0.1	< 0.1	< 1	< 1
	2	4/24/79	< 2.5	<0.0025	<0.0025	<0.0025	< 0.1	< 0.1	< 1	< 1
	3	5/09/79	2.3	0.0050	0.0025	0.0025	< 0.1	< 0.1	< 1	< 1
	4	6/04/79	2.5	<0.0025	0.0075	0.0025	< 0.1	< 0.1	< 1	< 1

TABLE A-11

MARE ISLAND

SAMPLING EFFORT NUMBER 1
March 8, 1979

ANALYSIS

TASK	Ag	As	Cd	Cr	Cu	Hg	Ni	PbI	PbII	PbIII	Se	Zn
Water Column (ug/L)	2.9	7.4	0.34	1.2	9.0	0.40	20	4.0	6.2	71	9.0	24
Suspended Particulates (ug/mg)												
Pass A ≥4u	1.0	7.8	6.0	97	110	1.6	140		Pb 20		42	190
Pass B 1u-4u	0.91	8.7	9.2	96	120	1.7	190		90		80	140
Pass C 0.07u-1u	1.4	6.4	11.7	170	130	1.9	310		190		79	160
Settled Particulates (ug/mg)	1.9	15	2.4	170	140	0.71	101	NO_3 1.0	30	NH_3 <0.05	4.9	90
Test Organisms (ug/g)												
Mytilus edulis	1.9	10	3.0	2.6	12	0.49	2.6		3.7		12	310
Corbicula fluminea	1.7	14	1.0	4.6	59	0.40	3.8		1.9		10	340
Bottom Sediments (ug/g)	2.7	24	1.7		97	0.60	64	NO_3 7	80	NH_3 860	2.1	160

TABLE A-12

MARE ISLAND

SAMPLING EFFORT NUMBER 2

March 23, 1979

ANALYSIS

TASK	Ag	As	Cd	Cr	Cu	Hg	Ni	PbI	PbII	PbIII	Se	Zn
Water Column (ug/L)	1.9	14	0.29	1.7	4.7	0.80	18	4.9	6.2	90	4.8	29
Suspended Particulates (ug/mg)									Pb			
Pass A ≥4u	1.7	6.4	5.9	100	110	0.9	160		24		49	210
Pass B 1u-4u	1.4	4.2	6.1	87	111	0.6	122		37		50	190
Pass C 0.07u-1u	2.0	4.1	1.0	110	160	1.0	290		109		82	290
Settled Particulates (ug/mg)	2.9	10	2.5	220	100	0.62	89	NO_3 4.1	45	NH_3 < 0.05	1.9	120
Test Organisms (ug/g)												
Mytilus edulis	2.3	12	3.1	5.0	16	0.33	3.4		2.9		13	300
Corbicula fluminea	2.2	9.1	< 1	3.4	7.8	0.42	3.2		1.6		12	290
Bottom Sediments (ug/g)	4.9	8	4.6		170	0.57	93	NO_3 6	57	NH_3 420	2.3	130

TABLE A-13

MARE ISLAND

SAMPLING EFFORT NUMBER 3
April 6, 1979

ANALYSIS

TASK	Ag	As	Cd	Cr	Cu	Hg	Ni	PbI	PbII	PbIII	Se	Zn
Water Column (ug/L)	2.7	6.8	0.30	6.0	4.2	1.0	26	<1.0	4.9	47	7.6	38
Suspended Particulates (ug/mg)									Pb			
Pass A >4u	1.9	5.0	2.3	86	130	0.4	190		49		7.0	190
Pass B 1u-4u	1.0	5.0	3.7	110	190	0.5	140		57		1.0	410
Pass C 0.07u-1u	2.4	2.4	5.9	140	210	0.7	220		72		2.1	260
								NO_3		NH_3		
Settled Particulates (ug/mg)	2.7	20	0.9	140	72	0.71	67	2.3	45	< 0.05	0.7	150
Test Organisms (ug/g)												
Mytilus edulis	0.8	8.0	4.2	10	13	0.67	3.4		2.8		9.4	270
Corbicula fluminea	1.3	8.1	1.2	3.3	7.7	0.32	3.6		2.2		9.8	230
								NO_3		NH_3		
Bottom Sediments (ug/g)	1.4	11	1.2	98	99	0.91	84	10	48	320	1.0	150
Artificial Substrate (ug/tube)	91	< 1	1	2.0	1.6	< 0.1	1.1		< 1		< 1	75

TOC = 33 Chlorophyll a = < 0.1 mg Volatile Solids = 70

TABLE A-14

MARE ISLAND

SAMPLING EFFORT NUMBER 4
May 7, 1979

ANALYSIS

TASK	Ag	As	Cd	Cr	Cu	Hg	Ni	PbI	PbII	PbIII	Se	Zn
Water Column (μg/L)	2.0	9.4	0.7	6.3	4.2	1.6	20	< 1.0	27	40	5.0	40
Suspended Particulates (μg/mg)												
Pass A ≥4μ	0.9	10	2.0	14	96	0.1	90		10		1.6	230
Pass B 1μ-4μ	0.9	9.0	3.0	21	120	0.8	40		10		4.2	210
Pass C 0.07μ-1μ	4.0	6.0	3.1	90	210	1.6	90		26		4.0	320
Settled Particulates (μg/mg)	3.0	6.4	0.4	100	110	< 0.1	50	NO_3 2.2	50	NH_3 1.9	1.0	190
Test Organisms (μg/g)												
Mytilus edulis	1.9	4	1.0	12	17	0.40	3.9		4.2		8.0	260
Corbicula fluminea	0.9	9	2.0	2.2	8.0	0.19	5.2		3.0		9.9	250
Bottom Sediments (μg/g)	1.7	11	1.6	43	110	0.90	80	NO_3 11	60	NH_3 280	2.0	170
Artificial Substrate (μg/tube)	0.9	4	1	1.2	2.0	< 0.1	4.0		< 2		< 1	90

TOC = 79 Chlorophyll a = 27 Volatile Solids = 90

TABLE A-15
PORT CHICAGO

SAMPLING EFFORT NUMBER 1
March 13, 1979

ANALYSIS

TASK	Ag	As	Cd	Cr	Cu	Hg	Ni	PbI	PbII	PbIII	Se	Zn
Water Column (μg/L)	0.6	5	0.8	0.9	3.1	0.30	20	1	10	67	7.1	24
Suspended Particulates (μg/mg)									Pb			
Pass A ≥4μ	2.3	6.9	4.5	31	90	0.8	160		40		7.2	160
Pass B 1μ-4μ	2.2	6.1	7.2	28	110	1.6	190		52		8.4	200
Pass C 0.07μ-1μ	4.1	5.6	9.8	56	330	2.4	210		63		13	200
Settled Particulates (μg/mg)	4.9	8.2	1.9	110	140	0.71	60	NO_3 < 0.05	56	NH_3 2.1	10	410
Test Organisms (μg/g)												
Corbicula fluminea	3.7	14	2.0	4.3	17	0.71	2.4		2.0		9.0	240
Bottom Sediments (μg/g)	4.7	14	4.4	290	170	1.0	110	NO_3 27	120	NH_3 390	5.2	310

TABLE A-16

PORT CHICAGO

SAMPLING EFFORT NUMBER 2
March 30, 1979

ANALYSIS

TASK	Ag	As	Cd	Cr	Cu	Hg	Ni	PbI	PbII	PbIII	Se	Zn
Water Column (ug/l)	2.4	11	1.1	1.9	4.0	0.60	18	< 1	5.2	42	9.0	23
Suspended Particulates (ug/mg)									Pb			
Pass A ≥4u	4.0	7.0	1.9	27	120	0.3	78		21		4.3	200
Pass B 1u-4u	1.2	7.0	1.6	48	210	0.8	140		27		9.2	220
Pass C 0.07u-1u	1.7	6.5	6.6	54	240	1.2	140		61		11	190
								NO_3		NH_3		
Settled Particulates (ug/mg)	5.6	7.5	1.4	140	130	1.2	94	< 0.05	42	< 0.05	12	520
Test Organisms (ug/g)												
Corbiclua fluminea	2.7	11.0	4.0	4.9	22	0.32	3.5		4.7		12	360
								NO_3		NH_3		
Bottom Sediments (ug/g)	3.0	12	4.3	420	160	1.0	100	28	94	2.0	1.8	330

TABLE A-17

PORT CHICAGO

SAMPLING EFFORT NUMBER 3
April 13, 1979

ANALYSIS

TASK	Ag	As	Cd	Cr	Cu	Hg	Ni	PbI	PbII	PbIII	Se	Zn
Water Column (ug/L)	4.0	14	0.50	1.7	9.0	0.78	32	< 1	4.7	100	6.0	47
Suspended Particulates (ug/mg)									Pb			
Pass A ≥4u	2.0	6.9	3.7	64	140	0.9	100		72		6.0	140
Pass B 1u-4u	1.9	7.7	9.0	69	190	1.7	140		60		8.2	210
Pass C 0.07u-1u	1.6	0.9	4.2	120	200	2.0	130		21		8.1	290
Settled Particulates (ug/mg)	1.9	6.9	2	170	100	0.40	52	NO_3 0.90	30	NH_3 2.4	8.1	460
Test Organisms (ug/g)												
Corbiclua fluminea	4.2	9.8	6.0	7.1	14	0.42	4.9		2.6		10	370
Bottom Sediments (ug/g)	2.9	12	7.0	20	120	1.3	96	NO_3 23	97	NH_3 400	1.4	400
Artificial Substrate (ug/tube)	1.0	< 1	1	2.4	2.1	< 0.1	2.0		< 1		< 1	70

TOC = 19 Chlorophyll a = < 0.1 Volatile Solids = 110

TABLE A-18
PORT CHICAGO

SAMPLING EFFORT NUMBER 4
May 14, 1979

ANALYSIS

TASK	Ag	As	Cd	Cr	Cu	Hg	Ni	PbI	PbII	PbIII	Se	Zn
Water Column (ug/L)	2.9	17	1.3	2.6	19	1.2	40	1	5.9	100	6.6	90
Suspended Particulates (ug/mg)									Pb			
Pass A >4u	2.3	5	2.5	30	110	0.6	100		40		3.3	160
Pass B 1u-4u	0.9	7	6.6	90	190	0.8	160		50		7.0	160
Pass C 0.07u-1u	2.9	15	10	190	240	1.9	150		70		9.2	260
Settled Particulates (ug/mg)	2.0	6.0	1.7	140	110	0.70	5.5	NO_3 < 0.03	40	NH_3 < 0.03	6.1	370
Test Organisms (ug/g)												
Corbiclua fluminea	3.4	14	5.0	7.7	9	0.50	6.0		2.7		12	310
Bottom Sediments (ug/g)	4.0	9	6.8	125	160	0.90	110	NO_3 40	75	NH_3 120	13	420
Artificial Substrate (ug/tube)	0.4	< 1	< 1	< 2	3.2	< 0.1	3.5		< 1		< 1	90

TOC = 56 Chlorophyll a = 40 Volatile Solids = 90

TABLE A-19
TREASURE ISLAND

SAMPLING EFFORT NUMBER 1
April 10, 1979

ANALYSIS

TASK	Ag	As	Cd	Cr	Cu	Hg	Ni	PbI	PbII	PbIII	Se	Zn
Water Column (μg/L)	1.7	6.0	0.69	4.9	6.7	0.32	47	1.0	4.0	27	2.9	49
Suspended Particulates (μg/mg)									Pb			
Pass A ≥4μ	4.0	8.0	1.6	190	140	1.2	120		60		4.2	120
Pass B 1μ-4μ	9.0	7.6	4.8	240	150	1.6	140		120		3.8	140
Pass C 0.07μ-1μ	14	8.2	5.0	280	190	2.9	190		140		3.4	170
								NO_3		NH_3		
Settled Particulates (μg/mg)	0.6	6.8	1.9	100	160	0.60	92	1.6	39	1.0	1.8	160
Test Organisms (μg/g)												
*Mytilus edulis**	1.2	7.0	2.0	1.7	7.2	0.20	2.9		4.0		9.0	190
Bottom Sediments (μg/g)	0.9	6.0	1.6	110	160	0.40	94		54		3.1	190

* These organisms collected from Point Richmond. Laboratory assays performed prior to these organisms being placed at the sampling site.

TABLE A-20

TREASURE ISLAND

SAMPLING EFFORT NUMBER 2
April 24, 1979

ANALYSIS

TASK	Ag	As	Cd	Cr	Cu	Hg	Ni	PbI	PbII	PbIII	Se	Zn
Water Column (μg/L)	2.0	4.5	0.47	5.0	5.2	0.30	29	0.3	2.0	22	8.9	47
Suspended Particulates (μg/mg)									Pb			
Pass A ≥4μ	2.3	8.9	2.4	94	130	0.7	180		50		2.1	120
Pass B 1μ-4μ	10	7.9	3.2	180	210	1.2	170		60		4.0	170
Pass C 0.07μ-1μ	20	12	3.7	210	240	1.8	240		190		4.0	160
								NO_3		NH_3		
Settled Particulates (μg/mg)	0.9	5.1	1.4	96	140	0.71	87	1.4	49	2.7	2.6	200
Test Organisms (μg/g)												
Mytilus edulis	1.1	7.0	6.0	1.6	9.8	0.60	2.3		4.6		6.1	190
Bottom Sediments (μg/g)	1.0	7.0	1.2	85	120	0.50	87		60		2.8	220

TABLE A-21

TREASURE ISLAND

SAMPLING EFFORT NUMBER 3

May 9, 1979

ANALYSIS

TASK	Ag	As	Cd	Cr	Cu	Hg	Ni	PbI	PbII	PbIII	Se	Zn
Water Column ($\mu g/L$)	2.4	11	0.50	4.8	5.0	0.60	32	< 1	< 1	12	6.9	35
Suspended Particulates ($\mu g/mg$)												
Pass A $\geq 4\mu$	2.7	12	5.0	70	160	1.1	90		70		1.9	110
Pass B 1μ-4μ	4.6	9.6	3.0	90	160	1.9	190		110		4.0	90
Pass C 0.07μ-1μ	19	9.0	10	120	230	2.4	130		160		10	160
Settled Particulates ($\mu g/mg$)	2.1	10	2.2	120	190	0.60	90	NO_3^- < 0.05	20	NH_3 < 0.05	3.8	200
Test Organisms ($\mu g/g$)												
Mytilus edulis	4.9	4.1	1.0	L.A.	14	0.7	6.4		3.5		4.9	230
Bottom Sediments ($\mu g/g$)	0.6	7.9	1.8	140	170	0.50	100	20	45	70	2.0	260
Artificial Substrate ($\mu g/tube$)	0.5	< 1	0.7	1.0	1.1	< 0.1	7		< 2		< 1	140

TOC = 240 Chlorophyll a = 4.0 Volatile Solids = 100

TABLE A-22

TREASURE ISLAND

SAMPLING EFFORT NUMBER 4
June 4, 1979

ANALYSIS

TASK	Ag	As	Cd	Cr	Cu	Hg	Ni	PbI	PbII	PbIII	Se	Zn
Water Column (μg/L)	1.3	7.8	0.90	6.8	10	0.21	55	< 1	< 1	22	12	40
Suspended Particulates (μg/mg)												
Pass A ≥4μ	6.0	6.0	1.0	60	120	0.9	70		42		1.7	110
Pass B 1μ-4μ	5.4	12	2.3	40	140	0.8	120		66		4.0	80
Pass C 0.07μ-1μ	22	15	10	170	300	1.9	160		170		9	240
Settled Particulates (μg/mg)	1.0	12	1.2	140	210	0.90	100	NO_3 < 0.05	36	NH_3 < 0.05	2.9	210
Test Organisms (μg/g)												
Mytilus edulis	1.1	5.6	2.0	1.1	1.9	0.43	8.2		2.2		2.0	220
Bottom Sediments (μg/g)	4.9	14	3.1	170	150	0.75	60	19	20	24	3.9	260
Artificial Substrate (μg/tube)	< 0.3	< 1	0.3	10.5	2.0	< 0.1	4		< 2		< 1	90

TOC = 300 Chlorophyll a = 9.0 Volatile Solids = 194 mg/tube

TABLE A-23

PARTICLE SIZE ANALYSIS

SAMPLING EFFORT NUMBER 1

% WEIGHT

Sieve Size (mm)

STATION		.600*	.425	.250	.180	.125	.075	.063	<.063
Mare Island 3/9/79	%	2.7	2.7	3.8	1.5	2.0	3.5	1.5	82.3
	Σ%	2.7	5.4	9.2	10.7	12.7	16.2	17.7	100.0
Port Chicago 3/14/79	%	5.6	2.0	4.0	3.4	5.6	4.5	1.5	73.4
	Σ%	5.6	7.6	11.6	15.0	20.6	25.1	26.6	100.0
Treasure Island 4/11/79	%	2.2	1.5	3.7	1.9	2.9	3.9	0.5	83.3
	Σ%	2.2	3.7	7.4	9.3	12.2	16.1	16.6	100.0

* Contained only organic debris and shell fragments.

TABLE A-24

PARTICLE SIZE ANALYSIS

SAMPLING EFFORT NUMBER 4

% WEIGHT

Sieve Size (mm)

STATION		.600*	.425*	.250	.180	.125	.075	.063	< .063
Mare Island	%	0.2	3.3	1.9	1.6	2.5	2.3	2.5	85.7
5/7/79	Σ%	0.2	3.5	5.4	7.0	9.5	11.8	14.3	100.0
Port Chicago	%	2.3	2.9	2.4	2.7	2.6	3.1	3.3	80.7
5/14/79	Σ%	2.3	5.9	2.7	10.3	12.9	16.0	19.3	100.0
Treasure Island	%	2.3	2.0	1.0	1.6	2.0	3.9	1.6	85.6
6/4/79	Σ%	2.3	4.3	5.3	6.9	8.9	12.8	14.4	100.0

*Shell and organic debris

TABLE A-27

Trace Element Content of Attached Organism

Area	Sampling Effort	Ag(R)	As(R)	Cd(R)	Cr(R)	Cu(R)	Hg(R)
Mare	3	7.8(.24)	< 1(<.01)	1(.01)	2.0(.03)	1.6(.05)	< 0.1(.003)
Island	4	6.9(.09)	4(.05)	1(.01)	1.2(.02)	2.0(.03)	< 0.1(.001)
Port	3	1.0(.05)	< 1(<.05)	1(.01)	2.4(.13)	2.1(.03)	< 0.1(.001)
Chicago	4	0.4(.01)	< 1(<.02)	< 1(<.02)	< 2 (.04)	3.2(.06)	< 0.1(.001)
Treasure	3	6.5(.03)	< 1(.004)	0.7(.002)	1.0(.004)	1.1(.004)	< 0.1(.0004)
Island	4	< 0.3(.001)	< 1(.004)	0.3(.001)	0.5(.04)	2.0(.01)	< 0.1(.0003)

Area	Sampling Effort	Ni(R)	PbI	PbII(R)	PbIII	Se(R)	Zn(R)
Mare	3	1.1(.03)	-	< 1	-	< 1	90(2.73)
Island	4	4.0(.05)	-	< 2	-	< 1	90(1.14)
Port	3	2.0(.03)	-	< 1	-	< 1	70(.89)
Chicago	4	3.5(.06)	-	< 1	-	< 1	90(1.61)
Treasure	3	7 (.03)	-	< 2	-	< 1	140(.58)
Island	4	4 (.01)	-	< 2	-	< 1	90(.30)

$R = \frac{\mu g\ element}{\mu g\ carbon}$

TABLE A-28

STATUS OF BIOCHEMICAL RESERVES

Area	Effort	% Dry Weight Glycogen 1	Glycogen 2	Glycogen $\bar{X}$	Lipid 1	Lipid 2	Lipid $\bar{X}$	Ratio Taurine/Glycine
Mytilus edulis								
Point Richmond Background	2/12/79	29	24	26.5	16	20	18	7.2
Mare Island	1	-	-	-	-	-	-	-
	2	12	10.8	11.4	16	20	18	10
	3	5.6	5.8	5.7	16	16	16	12
	4	4.1	3.7	3.9	16	19	17.5	10
Treasure Island	1	8.0	5.6	6.8	-	17	17	8.3
	2	5.6	7.2	6.4	19	22	20.5	9.0
	3	6.9	6.7	6.8	21	14	17.5	9.2
	4	4.2	4.2	4.2	18	20	19	9.5
Native Mussels from Piers		9.8	10.7	9.9	21	17	19	7.0
Corbicula fluminea								
Delta Background	2/20/79	16	16	16	14	17	15.5	5.8
Mare Island	1	-	-	-	-	-	-	-
	2	4.0	5.0	4.5	8	6	7	4
	3	4.2	5.3	4.7	8	7	7.5	3
	4	6.0	4.0	5.0	15	8	11.5	3
Port Chicago	1	3.9	3.8	3.8	10	14	12	6.1
	2	4.7	4.9	4.8	11	8	9.5	4.9
	3	4.2	4.7	4.5	16	10	13	5.2
	4	5.0	4.5	4.7	9	12	10.5	6.8

TABLE A-29. FAUNAL SAMPLES 1 AND 2 TAKEN AT MARE ISLAND STATION ON MARCH 9, 1979.

Sample # 1

Sieve Size	Species	Number
1.0 mm	*Macoma inquinata*	1
0.5 mm	Nematode	< 100
0.25 mm	None	

Sample # 2

Sieve Size	Species	Number
1.0 mm	None	
0.5 mm	*Streblospio benedicti*	1
	Oligochaete	2
0.25 mm	Harpacticoid	1
	Nematode	< 100

TABLE A-30. FAUNAL SAMPLES 1 AND 2 TAKEN AT MARE ISLAND STATION ON May 7, 1979.

Sample #1

Seive Size	Species	Number
1.0 mm	*Paraphoxus sp.*	1
	Ampelisca milleri	1
0.5 mm	Nematodes	< 25
0.25 mm	Nematodes	> 50

Sample #2

Seive Size	Species	Number
1.0 mm	None	
0.5 mm	Nematodes	> 25
0.25 mm	Nematodes	> 50

TABLE A-31. FAUNAL SAMPLES 1 AND 2 TAKEN AT PORT CHICAGO STATION ON March 14, 1979.

Sample #1

Seive Size	Species	Number
1.0 mm	Nematode	< 100
0.5 mm	Nematode	< 100
0.25 mm	Harpacticoid	1

Sample #2

Seive Size	Species	Number
1.0 mm	None	
0.5 mm	None	
0.25 mm	Harpacticoid	1

TABLE A-32. FAUNAL SAMPLES 1 AND 2 TAKEN AT PORT CHICAGO STATION ON May 14, 1979.

Sample #1

Seive Size	Species	Number
1.0 mm	None	
0.5 mm	Nematodes	< 50
0.25 mm	Nematodes	< 100

Sample #2

Seive Size	Species	Number
1.0 mm	None	
0.5 mm	Nematodes	< 10
0.25 mm	Nematodes	< 100

TABLE A-33. FAUNAL SAMPLES 1 AND 2 TAKEN AT TREASURE ISLAND STATION ON APRIL 10, 1979.

Sample #1

Sieve Size	Species	Number
1.0 mm	*Macoma nasuta*	1
	Capitella capitata	4
	Polynoidae	1
	Dorvillea rudolphi	1
	Hydroid colony	✓

Sample #2

Sieve Size	Species	Number
0.5 mm	Ostracod	1
	Exogone sp.	2
	Oligochaete	✓
	Nematode	> 150
0.25 mm	Nematode	> 100

TABLE A-34. FAUNAL SAMPLES 1 AND 2 TAKEN AT TREASURE ISLAND STATION ON JUNE 4, 1979.

Sample # 1

Seive Size	Species	Number
1.0 mm	*Macoma nasuta*	3
0.5 mm	Nematodes	>100
0.25 mm	Nematodes	>100

Sample #2

Seive Size	Species	Number
1.0 mm	*Macoma nasuta*	1
	Oligochaete	5
	Polychaete fragment	1
	Capitella capitata	1
0.5 mm	*Musculus senhousia*	1
	Exogone lourei	1
	Nematodes	>100
0.25 mm	Nematodes	>100

TABLE A - 35. LABORATORY TRACE METAL UPTAKE STUDY ON *Corbicula fluminea*, SHOWING MEAN CONCENTRATIONS AND STANDARD DEVIATIONS FOR DAYS 0 AND 10

		Cadmium[1]				Copper				Zinc			
Day	Statistic[2]	Tank 1	Tank 2	Tank 3	Tank 4	Tank 1	Tank 2	Tank 3	Tank 4	Tank 1	Tank 2	Tank 3	Tank 4
0	Mean	1.8	2.0	1.7	1.6	15	15	16	18	380	340	590	470
	Standard Deviation	0.35	0.57	0.28	0.28	0.71	2.8	1.4	2.8	79	130	78	17
10	Mean	0.54	0.67	0.62	0.68	15	14	16	14	340	580	210	350
	Standard Deviation	0.12	0.47	0.24	0.23	0.64	0.99	--	2.4	19	240	150	180

[1]Amounts of trace element (Cd, Cu & Zn), in µg/L, added to tanks are as follows: Tank #1, 0; Tank #2, 2.5; Tank #3, 5.0; Tank #4, 10.
[2]n=2.
[3]Tissue concentration (µg/g dry weight).

TABLE A-36. COMPARISON OF MEANS TEST USING STUDENT'S T. BACKGROUND VS. NATIVE *M. edulis*.

Element	t_s
Ag	0.163
As	1.410
Cd	17.918••
Cr	10.502••
Cu	3.228
Hg	0.205
Ni	7.543•
Pb	1.042
Se	3.268
Zn	5.275•

df = 2
• = ($P < 0.05$)
•• = ($P < 0.01$)

APPENDIX B

PILOT WATER QUALITY MONITORING STUDY
SAN FRANCISCO BAY AND DELTA

1. FIELD REPLICATION

Because the design of a long-term monitoring program is centered upon the acquisition of reliable data of sufficient precision, a prior knowledge of primary sources of variation is essential. The second pilot study suggested in Section 2 of this report is designed to assess those sources of variation in order that a long-term program might be designed in a cost-effective manner. In its essence, the pilot program incorporates replication at all levels of sampling and analysis, allowing at the program's conclusion, a design which maximizes effort at points of greatest variability.

The field sampling program is designed to obtain information to determine the number of field sample replications required for a long-term monitoring project. This program is to be performed at the three sampling sites used in the initial pilot study, Mare Island, Port Chicago and Treasure Island, and considers water column, suspended particulates, settled particulates and bottom sediment. Field replication of bivalve test organisms is discussed in section 3.6.5.

The emphasis of data acquisition will be to observe seasonal differences in the variation within and between daily tide cycles. The pilot study did not examine these aspects. The program design is compatible with examination by hierarchic analysis of variance. Such analysis has two major applications: (1) assessment of the magnitude of error at various levels of the sampling program, and (2) examination of the magnitude of variance attributable to various treatment levels in the study (Sokal and Rohlf, 1969).

In the program described below, each replicate water column sample will be analyzed for the following constituents: turbidity, ammonia, nitrate, nonfilterable residue and the trace elements silver, arsenic, cadmium, chromium, copper, mercury, nickel, lead, selenium, zinc and also polychlorinated biphenyls (PCBs). Suspended particulate samples will be divided into three size classes: (1) greater than 4 microns, (2) 1 to 4 microns and (3) 0.07 to 1 microns. For each of these three size classes, trace elements (the 10 recommended above) and PCBs would be analyzed.

(1) <u>Sampling locations</u>: Mare Island, Port Chicago, Treasure Island.

(2) <u>Sampling efforts</u>: quarterly for one year. January, April, July and October, using approximately 90-day intervals. The first two sampling efforts will be conducted during maximum precipitation intervals of the year. The third effort during July will reflect dry weather conditions. The fourth and final effort in October will complete the wet-dry weather cycles.

(3) Sampling period during each effort: five consecutive days (five consecutive 24-hour tidal cycles) with simultaneous sampling at all three sampling locations.

(4) Sampling frequency: two separate sets of five replicate field samples will be collected each day in the following manner: one set will be collected at high, high tide and the second set obtained at low, low tide; both for each 24-hour tidal cycle. Over the five consecutive days, a total of 25 high, high tide samples and 25 low, low tide samples will be collected per station location. Therefore, a total of 150 samples for each specified analysis per quarter will be collected.

In addition to the above sampling design, certain physical parameters should be monitored and samples of bottom sediment for replicate determination also be taken. Continuous monitoring of temperature, dissolved oxygen and salinity should accompany the water sampling. Five replicate samples for settled particulates and bottom sediment should also be collected during each sampling effort. Laboratory analysis of these samples will consist of the ten trace elements, ammonia and nitrates.

The above stated field program will require computation of a three-level hierarchic analysis of variance for each analysis. This will permit evaluation of the following sources of variation for statistical examination: among areas (sampling stations), among days within areas, among tidal cycles (high, high; low, low) within days and an error term of measurements (replicates) within the tide cycle.

The results from the hierarchic analysis can then be used in either one or both of the following ways to determine number of replicates.

(1) Using optimum allocation of resources (Cochran, 1968; Sokol and Rohlf, 1968) where cost is included to determine the "optimum" sampling design.

(2) Calculating the number of replicates needed to detect a given true difference between two means (Sokal and Rohlf, 1968). In this case, the investigator can select the degree of statistical sensitivity and calculate the corresponding number of replicates needed to detect a given true difference between means.

In addition, data generated from this sampling design may also be subjected to graphic analysis, factorial analysis of variance, least-significant-range tests between mean values, Student t test, and any other appropriate statistics that will aid in determining the number of field replications required.

The data acquired can also be used to investigate seasonal differences in the required number of field replications and differences in values at tidal extremes (high, high; low, low) and tidal cycles. This information can then be used to determine if sampling over subsequent tidal cycles is necessary in the long-term monitoring project, and which of the tide cycle extremes (high, high; low, low) ought to be sampled.

In the event that the cost precludes 150 quarterly determinations per parameter sampled, reduction in sample number can be accomplished in the following manner. First, decrease the number of consecutive sampling days from five to four in each location. The number of quarterly determinations per parameter is reduced to 120. Further reduction can be effected by decreasing the number of field replicate samples from five to four, which will yield a total of 90 quarterly determinations per parameter. Further reduction is not recommended. To fully utilize this hierarchic design, sample replication at all levels is necessary to critically investigate the issue of number of field replicates for the long-term monitoring project.

Once samples have been collected, each subsampling, digestion and other laboratory procedures could be replicated, though only for the first day of sampling at each of the three sites. Analysis could be accomplished by continuing the ANOVA design described above down through all levels of laboratory procedure. The greatest sources of variation might then be identified and the program streamlined by decreasing or eliminating replication at levels which contribute little to the total variance.

Though data were not generated in the previous pilot study to quantify such speculation, it is anticipated that many of the more routine analyses, such as ammonia, nitrate and turbidity would have much lower coefficients of variation than analyses of biological specimens or dynamic sediment systems. Thus it is likely that considerably more replication of measurements made on the latter systems would be necessary.

TABLE B-1. PROPOSED FIELD SAMPLING DESIGN TO BE REPEATED EACH QUARTER (FOUR TIMES PER YEAR), WITH NOTATION INDICATING ANOVA DESIGN

	Day[2] #1		Day #2		Day #3		Day #4		Day #5	
Sampling Location[1]	HH Tide[3] (measurements)[4]	LL Tide[3] (measurements)	HH Tide (measurements)	LL Tide (measurements)	HH Tide (measurements)	LL Tide (measurements)	HH Tide (measurements)	LL Tide (measurements)	HH Tide (measurements)	LL Tide (measurements)
Mare Island										
Port Chicago										
Treasure Island										

[1]Sampling Location (a=3) (station location is highest level of classification).
[2]Days (b=5); days are consecutive with simultaneous sampling at each location.
[3]Tides (c=2); HH = High, High; LL = Low, Low.
[4]Measurements (n=5).